



NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

**ADDITIVE MANUFACTURING: PREPARING
FOR THE REALITY OF SCIENCE FICTION**

by

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September 2015

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**ADDITIVE MANUFACTURING: PREPARING FOR THE REALITY OF
SCIENCE FICTION**

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ABSTRACT

Historically, policymakers have had difficulty addressing issues raised by emerging technologies. Whether it is inadequate legislation due to a general lack of awareness, or overregulation from a perceived threat, emerging technologies seem to repeatedly confuse those responsible for ensuring their safe incorporation into society. Despite decades of experience with similar issues, this trend continues to this day. What lessons can be drawn from different approaches to policy development for other emerging technologies to help policymakers avoid these failures for additive manufacturing technologies?

A structured focus comparison of three emerging technologies, unmanned aerial systems, autonomous vehicles, and additive manufacturing, revealed characteristics of emerging technologies—such as a low price point for market entry and rapid evolution—that tend to surprise policymakers.

This thesis recommends organizations make a concerted effort to engage early and often in the policy development process, and that they carefully consider each stakeholder's level of involvement. It is also recommended that the Department of Homeland Security leverage existing mechanisms, such as the Centers of Excellence partnerships and the Strategic Foresight Initiative, to engage nontraditional partners in addressing issues raised by additive manufacturing technologies.

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LIST OF ACRONYMS AND ABBREVIATIONS

ARPA	Advanced Research Projects Agency
CAD	Computer-aided Design
CIA	Central Intelligence Agency
CEO	Chief Executive Officer
COE	Centers of Excellence
CSC	Computer Science Corporation
DARPA	Defense Advanced Research Projects Agency
DDTC	Directorate of Defense Trade Controls
DHS	Department of Homeland Security
DLP	Digital Light Processing
DOD	Department of Defense
DOJ	Department of Justice
EOC	Emergency Operations Center
FCO	Federal Coordinating Officer
FAA	Federal Aviation Administration
FDM	Fused Deposition Modeling
FEMA	Federal Emergency Management Agency
FMVSS	Federal Motor Vehicle Safety Standards
GM	General Motors
GPS	Geospatial Positioning System
GWOT	Global War on Terror
IACP	International Association of Chiefs of Police
ICTAF	Interdisciplinary Center for Technology Analysis and Forecasting

NHTSA	National Highway Traffic Safety Administration
NRA	National Rifle Association
OPPA	Office of Policy and Program Analysis
R&D	Research and Design
S&T	Science and Technology
SAFE	Secure Ammunition and Firearms Enforcement Act
SFI	Strategic Foresight Initiative
TRIP	Trade-related Aspects of Intellectual Property Rights
UFA	Undetectable Firearms Act
UAS	Unmanned Aerial Systems
UAV	Unmanned Aerial Vehicle
UCA	University of Central Arkansas
USDOT	United States Department of Transportation
WWI	World War I
WWII	World War II

EXECUTIVE SUMMARY

The relationship between public policy and emerging technologies has often been viewed as incompatible. In some ways, this view is in fact, accurate. Historically, governments faced with the complexity and ambiguity of an emerging technology, have applied regulatory mechanisms to contain or control the technology's potentially nefarious uses. Conversely, however, some governments have used various tools within their control to support and promote innovation, ultimately resulting in new technologies. These historical examples also illustrate how the policy development approaches taken by legislative bodies can significantly impact emerging technologies' trajectories. So what can policymakers learn from the successes and failures of historical, technology-focused legislation to help them develop an informed approach to future emerging technology concerns?

The primary focus of this project is answering that question for one of today's most popular emerging technologies: the 3D printer.

To appropriately address the question, this research used a structured, focused comparison to examine select elements of unmanned aerial systems (UASs), autonomous vehicles, and additive manufacturing systems. These technologies were selected based on availability of academic research as well as pertinence in the field of homeland security. To strengthen the approach to this qualitative study, the methodology focused on reducing the number of variables considered in each selected technology, and choosing emerging technologies that possessed similar conditions.

This research revealed that the unique, individual characteristics of each emerging technology are the most significant factors that can lead to uninformed or reactionary public policy approaches. The most significant characteristics revealed by this study were:

- timeframe for evolution of technology
- price point for entry into the market
- range of impacted stakeholders

This research showed that quickly evolving technologies with low price points for entry into the market and wide ranges of interested or impacted stakeholders are the most likely to surprise legislators. UASs and additive manufacturing technologies fit this description and, to date, have not been adequately addressed by policymakers.

From these findings, the researcher developed recommendations at two levels: strategic and tactical. The strategic-level recommendations focus on general lessons learned from historical policy development examples focused on emerging technologies. These are high level, generalizable, and suitable for any organization interested in working with emerging technologies. The tactical-level recommendations are focused on existing mechanisms within the Department of Homeland Security (DHS) that can be leveraged to specifically address potential policy questions raised by the recent advancements in additive manufacturing processes. These recommendations aim to be realistic and executable, with consideration given to the continued strain on resources available for new initiatives.

(1) Strategic Recommendations

- Organizations should engage with stakeholders early and often in the policy development process.
- Organizations should take a deliberate approach to engaging with non-traditional stakeholders.
- Organizations should promote an environment in which policy entrepreneurs can test various potential policy solutions prior to implementation.

(2) Tactical Recommendations

- The Department of Homeland Security should leverage existing mechanisms to further examine the potential policy implications of advancements in additive manufacturing technologies.
- DHS Science and Technology Directorate should utilize its Centers of Excellence network to engage academia in research involving the nexus between homeland security and additive manufacturing.

- The Federal Emergency Management Association should address the potential implications of additive manufacturing and other emerging technologies in its Strategic Foresight Initiative.

This research is not only limited to the previously identified technologies, but also to the current state of policy development. As these technologies mature and more academic literature becomes available, future research could analyze a larger number of technologies and a more expansive subset of examined elements. As new policies are developed and implemented addressing not only additive manufacturing but other emerging technologies, this research should be revisited and updated.

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I. INTRODUCTION

A quick Internet search for bad public policy examples will almost immediately, depending on one's Internet speed, result in hundreds of thousands of hits. Popular results include the 18th Amendment in 1917, prohibiting the manufacturing, transportation, and sale of intoxicating liquors, and the 2009 Car Allowance Rebate System, more commonly referred to as "Cash for Clunkers." But what public policy characteristics separate the bad from good?

For the purpose of this paper, a bad public policy is an uninformed policy created to address one public concern, but which unintentionally creates several others.¹ In his *Boston Globe* column, John E. Sununu observes this can occur when policymakers "focus on the kind of vague simplicity that has great political appeal but tends to disintegrate as soon as it comes into contact with the real world."² Often, this focus on the vague simplicity becomes more apparent when legislators attempt to address complex issues pertaining to emerging technology. As the following narrative illustrates, a popular emerging technology, the personal 3D printer, is already poised to confound policymakers unaware of its complexities and its potential.

A. BACKGROUND: CODY WILSON'S STORY

On an uncharacteristically mild Texas day in May 2013, a young man standing amid dry desert dirt and a few small clumps of grass stares intently at an unknown object in the distance. He is of average height and build and nothing about his dress is particularly striking; he wears blue jeans, a plain black polo, and a brown ball cap. After a few seconds of motionless focus, he glances over to a video camera to ensure its operator is set. He makes a few small adjustments to his sunglasses, leans forward, raises

¹ "Prohibition," History.com, accessed July 6, 2015, <http://www.history.com/topics/prohibition>; Ted Gayer and Emily Parker, "Cash for Clunkers: An Evaluation of the Car Allowance Rebate System," Brookings Economic Studies, October 31, 2013 <http://www.brookings.edu/research/papers/2013/10/cash-for-clunkers-evaluation-gayer>.

² John E. Sununu, "Cash for Clunkers: How Bad Public Policy gets Made," *Boston Globe*, September 1, 2014, <https://www.bostonglobe.com>.

his arms, and, with a muffled “pop,” fires what appears to be an oddly shaped toy gun.³ This young man’s name is Cody Wilson. The gun he just fired, nicknamed the *Liberator*, is no toy, and the results of his initial test just solidified his position on *Wired Magazine*’s list of the 15 Most Dangerous People in the World.⁴

While Cody Wilson’s complete biography is not critical for the purposes of this paper, his background and ideological perspectives offer helpful insight into the heated public debate surrounding his use of an emerging technology.

Cody Wilson was born in January 1988 in Little Rock, Arkansas to parents that he described as, “your mainstream Arkansan conservative types.”⁵ “It wasn’t until college,” said, “that I went ahead and said: ‘You know what? I’m an anarchist.’ I’ve always been on the Internet, but basically my zeal for the Internet and my anarchist tendencies all kind of cross-pollinated. I discovered crypto-anarchy and the cypherpunks and Internet radicalism.”⁶

It was also during his time at the University of Central Arkansas that Wilson would meet and befriend many individuals who would help him establish Defense Distributed—the company credited for developing the first shareable blueprint for a 3D-printed weapon. In a video posted on YouTube, Wilson attempts to explain the company’s initial goals:

A group of friends and I have decided to band together under a collective name. We’re not a company, we’re not a corporation, we’re not even a business association of any kind. We just call ourselves Defense Distributed. We want to share with you an idea. This idea is not original. This idea has been had before. But it’s an idea whose time has come. We think we have a way to get there. The Defense Distributed project has

³ “Liberator—The Dawn of Wiki-Weapons,” YouTube video, 0:52, posted By “Defense Distributed,” May 2013, <https://www.youtube.com/watch?v=drPz6n6UXQY>.

⁴ Robert Beckhusen, “The 15 Most Dangerous People in the World,” *Wired*, December 19, 2012, <http://www.cbsnews.com/news/liberator-gun-made-with-3d-printer-fires-first-successful-shot/>

⁵ “Cody Wilson: Troll, Genius, Patriot, Provocateur, Anarchist, Attention Whore, Gun Nut or Second Amendment Champion?” *Arkansas Times*, January 09, 2014, <http://www.arktimes.com/arkansas/cody-wilson-troll-genius-patriot-provocateur-anarchist-attention-whore-gun-nut-or-second-amendment-champion/Content?oid=3173005&showFullText=true>.

⁶ Ibid.

developed an idea we're calling the Wiki Weapon. It would be the world's first 3D-printable personal defense system.⁷

Defense Distributed did not immediately set out to create a complete and fully functional 3D-printable gun, but instead focused on creating individual firearm components that could be attached to weapons created through standard manufacturing techniques. The component that drew the most attention in the media was a plastic receiver for the AR15—a category of semi-automatic assault rifle that is owned by millions of private civilians in the United States.⁸ The receiver is the particular section of the rifle that contains the serial number—the only way a firearm can be traced by the Bureau of Alcohol, Tobacco, Firearms, and Explosives' (ATF) National Tracing Center.⁹ By developing the blueprints for a receiver that could be manufactured privately and without a serial number, Defense Distributed essentially eliminated the primary mechanism for the federal government to trace specific types of assault rifles.

While Defense Distributed was perfecting its design for the AR15 receiver, Adam Lanza used the same style weapon in his deadly assault on the Sandy Hook elementary school in Newtown, Connecticut.¹⁰ The tragedy, which claimed the lives of 20 students and six adults, quickly spurred Congress into action. In January 2013, New York Governor Andrew Cuomo signed into law the New York Secure Ammunition and Firearms Enforcement (SAFE) Act, which, among other things, placed a ban on high-capacity magazines and assault weapons.¹¹ Defense Distributed, in response, released several free plans for printable high-capacity magazines. These plans included a

⁷ "Cody Wilson," *Arkansas Times*.

⁸ William J. Krouse, *Gun Control Legislation* (CRS Report No. RL32842) (Washington, DC: Congressional Research Service, 2012), 8.

⁹ "National Tracing Center," Bureau of Alcohol, Tobacco, Firearms, and Explosives, last modified June 19, 2015, <https://www.atf.gov/content/firearms/firearms-enforcement/national-tracing-center>.

¹⁰ "Sandy Hook Shooting: What Happened?" CNN, accessed April 17, 2015, <http://www.cnn.com/interactive/2012/12/us/sandy-hook-timeline/>.

¹¹ Andrew Cuomo, "Governor Cuomo Signs Groundbreaking Legislation That Will Give New York State the Toughest Protections against Gun Violence in the Nation," January 15, 2013, <https://www.governor.ny.gov/news/governor-cuomo-signs-groundbreaking-legislation-will-give-new-york-state-toughest-protections>.

magazine for the AR15 nicknamed the “Cuomo” and another for the AK47 dubbed the “Feinstein” after vocal gun control advocates in Congress.¹²

Only three months after the New York SAFE Act was signed into law, a New York Congressman attempted to specifically address the issue of 3D printed guns via legislation. In April 2013, Congressman Steve Israel introduced a bill that sought to overhaul the then-current Undetectable Firearms Act (UFA) of 1988. The revisions, which required permanent metal pieces inside all firearms, specifically targeted 3D printed guns, which are known for having removable metal inside their grips just large enough to be identified by metal detectors.¹³ The proposed provisions to the UFA addressing concerns related to 3D printed guns were not passed; the then-current UFA was simply extended another ten years.¹⁴

It was in the midst of this political focus on gun control that Defense Distributed turned its attention to developing a fully-functional 3D printed weapon, Cody Wilson’s famed *Liberator*. By May 2013, the company had posted a YouTube video of Wilson successfully test-firing the weapon. This was a pivotal moment for the company, and its founders knew it. In an interview, Wilson noted, “At the end of the day, we realized the political reality, which is that this is something that at least the current administration doesn’t want to happen. They have a real antipathy for it. So at any opportunity, if you messed up, that’s a point of criminal investigation or prosecution.”¹⁵

After the successful test of the *Liberator*, Defense Distributed released the computer-aided design (CAD) file for the weapon via the Internet. Within a week, the State Department’s Directorate of Defense Trade Controls (DDTC) requested that these files, along with others closely associated with Defense Distributed, be taken down. The DDTC claimed the technology could be used to violate laws regarding the international

¹² “Cody Wilson,” *Arkansas Times*.

¹³ Derek Mead, “Congress’s Plastic Gun Ban Left a 3D-Printed Loophole,” *Motherboard*, December 10, 2013, <http://motherboard.vice.com/blog/congress-plastic-gun-ban-left-a-3d-printed-loophole>.

¹⁴ Burgess Everett, “Senate Passes Legislation on Undetectable Guns,” *Politico*, December 9, 2013, <http://www.politico.com>.

¹⁵ “Cody Wilson,” *Arkansas Times*.

export of approved firearms.¹⁶ Fearing serious prosecution, Wilson complied, but not before the file for the *Liberator* was downloaded over 100,000 times.¹⁷

The media's reactions to Defense Distributed's actions and to the *Liberator* have been varied. *Computerworld Magazine* claims to have tested the *Liberator* and concluded the devices were "far more dangerous for the shooter than the intended target."¹⁸ Conversely, *Daily Mail* reported that 3D weapons, once basic and unreliable, are now "deadly."¹⁹ The political response has not been much different. Democrats tend to support stricter gun laws and, as such, have been strong opponents of 3D printed guns. At a press conference announcing a measure to make 3D printed guns illegal, Senator Charles Schumer stated, "A terrorist, someone who's mentally ill, a spousal abuser, a felon can essentially open a gun factory in their garage."²⁰ On the contrary, it was pressure from the National Rifle Association (NRA) and members of the Republican Party that helped strike down the addition of stricter language in the UFA in 2013.²¹

While the debate surrounding 3D printed guns has received both media and political attention, there is a related debate currently underway that has much larger implications: the government's role in 3D printing as an emerging technology and as an established industry. Vocal individuals on many sides of the issue are arriving at conclusions and presenting potential recommendations based on misconceptions about current (and potential future) technological capabilities of 3D printing. Cody Wilson's

¹⁶ Michael Molitch-Hou, "Defense Distributed Sues State Department for Freedom of 3D Printable Gun Speech," 3D Printing Industry, May 7, 2015, <http://3dprintingindustry.com/2015/05/07/defense-distributed-sues-state-department-for-freedom-of-3d-printable-gun-speech/>.

¹⁷ Ibid.

¹⁸ Lucas Mearian, "Lab Tests Show 3D Printed Guns Can Be Useless—and Dangerous," *Computerworld*, May 30, 2014, <http://www.computerworld.com/article/2490074/emerging-technology/lab-tests-show-3d-printed-guns-can-be-useless---and-dangerous.html>.

¹⁹ Jonathan O'Callaghan, "The Terrifying Reality of 3D-Printed Guns: Devices that Anyone Can Make are Quickly Evolving into Deadly Weapons," *Daily Mail*, May 16, 2014, <http://www.dailymail.co.uk/sciencetech/article-2630473/The-terrifying-reality-3D-printed-guns-Devices-ANYONE-make-quickly-evolving-deadly-weapons.html>.

²⁰ "Schumer Announces Support For Measure To Make 3D Printed Guns Illegal," CBS New York, May 5, 2013, <http://newyork.cbslocal.com/2013/05/05/schumer-announces-support-for-measure-to-make-3d-printed-guns-illegal/>.

²¹ Ibid.

story exemplifies how an underappreciated emerging technology combined with misinformation can lead to uninformed policy. What the vast majority of media reports and political oratory are missing is an unbiased analysis of the pertinent technologies and the potential implications for the various stakeholders who must decide the fate of these technologies in the United States.

B. PROBLEM STATEMENT AND RESEARCH QUESTIONS

Advancements and access to emerging technologies, including additive manufacturing, over the last five years have many experts believing the world is about to witness the start of another industrial revolution.²² The relative ease with which complex designs are created, along with the continued decline in manufacturing costs associated with this technology, has convinced these same experts that, in the near future, individuals will be producing many of their basic needs from the privacy of their own home. Whether or not these predictions come to fruition, it is apparent that the recent advancements in additive manufacturing technologies have serious policy implications across multiple industries. Copyright and intellectual property rights concerns have been at the forefront of these discussions, but high-profile stories involving the development and release of plans for non-metallic weaponry have attracted the attention of policymakers—especially in the United States.

As policymakers slowly gain an appreciation for this technology’s legislative complexities, the technology itself is advancing faster than the rulemaking process. While lawmakers consider the implications of a single-shot, plastic gun developed by a few individuals fresh out of college, research firms and universities are getting closer to bioprinting human organs.²³ Gartner, a research center focused on global technology issues, has been heavily involved in additive manufacturing research over the last five years. One of Gartner’s research directors, Pete Basiliere noted, “Most of the [bioprinting]

²² Aaron Council and Michael Petch, *3D Printing: The Rise of the 3rd Industrial Revolution*, Gyges3d.com: Kindle Edition, 2014.

²³ Mary-Ann Russon, “3D Printers Could be Banned by 2016 for Bioprinting Human Organs,” *International Business Times*, January 29, 2014, <http://www.ibtimes.co.uk/3d-printers-could-be-banned-by-2016-bioprinting-human-organs-1434221>.

research is being done in universities and start-ups. It's not really ready for the big time yet and in some cases, the research is far ahead of government agency approval.”²⁴ This scenario is not new. As this paper illustrates, other emerging technologies, such as unmanned aerial systems (UAS) and autonomous vehicles, have caught policymakers by surprise in the past, as others no doubt will in the future. Legislators are often scrambling to quickly address the most immediate issues, which leaves little or no time to identify lessons learned and best practices to help government leaders better prepare for the next emerging technology. This type of reflection needs to occur; inadequate or misinformed public policy could have serious security and economic impacts on the future proliferation of an emerging technology such as additive manufacturing. In an attempt to address these concerns, this research seeks to answer a few important questions.

(1) Primary Research Question

What lessons can the United States government learn from the emergence of unmanned aerial systems and autonomous vehicles to better prepare a more-informed public policy to accompany new additive manufacturing technologies?

(2) Secondary Research Questions

What are the barriers to the development of informed public policy pertaining to emerging technologies? What processes can be utilized to help policymakers and the public better understand the implications of policy in emerging technologies?

C. SIGNIFICANCE TO THE FIELD

This necessary research will help stakeholders understand how public policy impacts and shapes the trajectory of emerging technologies. Homeland security practitioners are in a somewhat unique position; they are often at the forefront of emerging technologies, tasked to incorporate new tools into their daily missions, but also expected to protect the public from the misuse of these same technologies. The homeland security practitioner's central missions are based on the rule of law. Inadequate or

²⁴ Ibid.

nonexistent policies pertaining to these emerging technologies not only impact the mission effectiveness, but can also endanger the lives of both the practitioner and the public. As the rate of technological adoption continues to accelerate, it will become increasingly important for policymakers to identify processes by which they can better address the ever-evolving homeland security concerns created by emerging technologies.

D. METHODOLOGY AND LIMITATIONS

This research uses a structured, focused comparison to examine select elements of unmanned aerial systems, autonomous vehicles, and additive manufacturing systems. This methodology is designed to produce generalizable knowledge about causal questions related to the interaction between public policy and emerging technologies. To further strengthen the qualitative approach, the research focused on reducing the number of variables considered in each of the selected technologies, and choosing examples of emerging technologies that possess highly similar conditions.²⁵ While all three technologies are examined using this methodology, the author's recommendations focus on issues related to additive manufacturing.

This research examines how lessons learned from other emerging technologies can better inform public policy related to additive manufacturing technologies. The methodology identifies policy similarities and differences among a select number of emerging technologies, selected based on availability of academic research as well as pertinence to the field of homeland security. This analysis is limited to unmanned aerial systems and autonomous vehicles, namely historical development, future drivers of technological maturation, and current policy considerations. As these technologies mature and more literature is available, future research could analyze more technologies and a more expansive subset of elements. This research is a snapshot in time of current public policy; as new policies are developed and implemented addressing not only additive manufacturing, but other emerging technologies, this research should be revisited and updated.

²⁵ Alexander George and Timothy J. McKeown, "Case Studies and Theories of Organizational Decision Making," in *Advances in Information Processing in Organizations*, vol. 2, 21–58 (JAI Press, 1985).

II. LITERATURE REVIEW

Although additive manufacturing was first commercialized over 20 years ago, recent technological advancements associated with personal 3D printers have led many experts to believe the process will have significant global implications across numerous sectors within the next 3–5 years.²⁶ This literature review examines a selection of sources pertinent to continued research about additive manufacturing and the potential future of the industry. While much has been written on additive manufacturing’s somewhat brief history and rapid technological advancements, the focus of this review is primarily limited to the classification of the available literature and areas open for additional research.

The sources for this review have been arranged under the following topical areas:

- common language framework for additive manufacturing
- current capabilities and future applications of additive manufacturing
- potential legal implications
- implications for national and homeland security

Sources contained in this review range from professional journals to industry experts’ personal blogs. The sheer number of available sources has exploded in the last five years due primarily to the industry’s accelerated growth and presumed future potential in the global marketplace. A plethora of information is currently available about methods, processes, and varying techniques of additive manufacturing, but there are also glaring shortfalls in available literature on related topics. This is especially apparent when one is focused on obtaining sources from academia (a topic that will be addressed later in this paper).

²⁶ Terry Wohlers and Tim Gomet, “Additive Manufacturing and 3D Printing State of the Industry,” in *Wohlers Annual Report 2011* (Fort Collins, CO: Wohlers, 2011).

A. A LANGUAGE FRAMEWORK FOR ADDITIVE MANUFACTURING

Before engaging in an informed discussion, stakeholders must have a common frame for the language used by industry experts and, if applicable, mass media. This lack of a common framework for discussing additive manufacturing and associated technologies is a consistent theme across many sources. For example, the term “3D printer” currently carries several very different definitions, depending on the source of the material. Some authors use it as an umbrella term for any device used to produce 3D objects, while other sources use the term to distinguish a low-cost, low-capability device from the much higher-end, higher-capability devices. This simple point of confusion has made translating information to non-technical stakeholders challenging. Despite an established industry standard definition for additive manufacturing, “to this day, there isn’t a universal agreement on the definition of 3D printers.”²⁷ The *Wikipedia* page, often the first result in a Google search for the term, defines 3D printing as, “3D printing or additive manufacturing [emphasis added],” insinuating the terms may be used interchangeably.²⁸ Other terms, such as “rapid prototyping” and “rapid tooling,” appear in literature and, because of the context in which they are used, often further complicate the terminology agreement.²⁹

As noted previously, an official industry standard definition does, in fact, exist for additive manufacturing. Industry leaders and technical experts worked together to develop a short glossary of the most common terminology; interestingly enough, however, only a few have incorporated these standard definitions into published documents. Joe Hiemenz of Stratasys, an industry leader in additive manufacturing, acknowledges the distinction between the different types of technology is unclear.³⁰ He does, however, identify one framework that has become more popular than most among

²⁷ Joe Hiemenz, *3D Printers vs. 3D Production Systems* (Eden Prairie, MN: Stratasys, 2010).

²⁸ “3D printing,” Wikipedia, http://en.wikipedia.org/wiki/3D_printing.

²⁹ Paul F. Jacobs, *Stereolithography and other RP&M Technologies: From Rapid Prototyping to Rapid Tooling* (New York: Society of Manufacturing Engineers, 1995).

³⁰ Hiemenz, *3D Printers vs. 3D Production System*, 3.

industry leaders and technical experts. This framework, used throughout this paper, identifies and defines three core terms:

- **Additive Manufacturing**—an umbrella term for the process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies (ASTM F2792)³¹
- **3D Printer**—a compact, low-cost, and easy-to-use device for entry-level additive manufacturing methods³²
- **3D System**—larger, more complex, and more expensive systems designed for high-end functionality³³

Again, it should be noted that, outside of the industry standard, sources' terminology and definitions vary greatly. In a more informal effort to address this disparity, 3D Printing Headquarters has created an online glossary specific to the additive manufacturing industry. The glossary includes hundreds of terms and the company updates its page by actively requesting additional information from readers about terms that may be missing from its database.³⁴ While this wiki-style approach is much quicker and more collaborative than a more formal process, it still does not resolve the need for standard industry definitions. Establishing a common glossary of terms for industry experts as well as researchers remains an unresolved issue.

New blogs and websites seem to be popping up daily, and many are created by individuals claiming to be experts in the field of 3D printing. Without an agreed-upon set of common terms and definitions, however, it is difficult to differentiate between sources of information that are reliable and those that are not.

³¹ "What Is Additive Manufacturing?" Wohler, accessed August 11, 2015, <http://wohlersassociates.com/additive-manufacturing.html>.

³² Richard Hague and Phil Reeves, "Additive Manufacturing and 3D Printing," *Ingenica*, no. 55, June 2013.

³³ Hiemenz, *3D Printers vs. 3D Production System*, 3.

³⁴ Jason King, "3D Printing Glossary," 3D Printing, April 12, 2014 <http://3dprinthq.com/3d-printing-glossary/>.

B. CURRENT CAPABILITIES AND FUTURE IMPLICATIONS

Of the topics examined in this literature review, the current capabilities and future applications of additive manufacturing are some of the most heavily debated. There are several reasons for this debate, but the two main sources of contention recognized in this review are the aforementioned issues regarding common language, the technology's current limitations, and the speed at which the technology is changing.

In his article, "Why 3D Printing is Overhyped," Nick Allen, the founder of a 3D printing company in London, argued there are several key factors to consider before believing in the so-called "3D printing revolution."³⁵ The three elements central to his argument (and the argument of several sources) are³⁶:

- **Strength**—because of the techniques used in additive manufacturing (layer-by-layer), 3D printed parts are inherently weaker than parts manufactured using traditional methods (subtractive manufacturing).
- **Speed**—current technology requires hours, or even days, to produce items that can be made in minutes using traditional methods.
- **Cost**—for this process, cost is primarily based on type and amount of materials used (not complexity). This means that it would be much more expensive to produce larger, less complex products via this process.

In direct response to these statements, other self-proclaimed field experts argue that Allen's assertions about the technology's current capabilities are completely wrong, and that these systems are far more advanced than he acknowledges (in exploring these arguments, this thesis does not distinguish between 3D printers for personal use and those for commercial use or 3D systems as defined earlier in this paper). This creates confusion among Allen's intended audience and those who responded to his article.³⁷ Allen's arguments, which seem to be valid, are overshadowed by the lack of clarity in his writing. This level of ambiguity is also evident in other sources, such as corporate web pages and, more importantly, reports from journalists who are not subject-matter experts in the field.

³⁵ Nick Allen, "Why 3D Printing Is Overhyped (I Should Know, I Do it for a Living)," *GIZMODO.com*, last modified May 17, 2013, <http://gizmodo.com/why-3d-printing-is-overhyped-i-should-know-i-do-it-fo-508176750>.

³⁶ Ibid.

³⁷ Ibid.

In addition to the confusion surrounding terminology, descriptions about current capabilities, limitations, and future implications of additive manufacturing vary widely. In the review of selected sources, no clear pattern of predictions emerged from any single group. Opinions varied greatly between known industry experts and academia. On one end of the spectrum, there are those who predict the technology will change manufacturing techniques, processes, and associated economies on a global level.³⁸ At the other end are those who foresee a much more restricted use of the technology with complex 3D systems remaining in the hands of large companies and cheaper 3D printers being restricted to hobbyists.³⁹

In a report on the current capabilities and future implications of 3D technology, researchers at Computer Science Corporation (CSC), Vivek Srinivasan and Jarrod Bassan, listed the top trends to watch for in 3D printing. In part, their final list predicted that:

- **3D printing will become industrial strength**—no longer reserved for prototypes, but full-scale production of components.
- **3D printing will start saving lives**—medical implants could eventually reduce or eliminate the organ donor shortage.
- **3D print shops will open at the mall**—3D printing will become localized and fast enough for the consumer marketplace.
- **Heated debates will arise over property rights**—as consumers purchase and then modify products, manufacturers will have to grapple with the prospect of their copyrighted designs being copied.
- **Digital literacy will increase**—your children will bring home 3D printed projects and more schools will adopt the technology as prices continue to fall.⁴⁰

³⁸ Christopher D. Winnan, *3D Printing: The Next Technological Gold Rush* (Christopher D. Winnan, 2012), 228.

³⁹ Thomas Campbell, Christopher Williams, Olga Ivanova, and Banning Garrett, *Could 3D Printing Change the World?: Technologies, Potentials, and Implications of Additive Manufacturing* (Strategic Foresight Report) (Washington, DC: Atlantic Council, 2011).

⁴⁰ Vivek Srinivasa and Jarrod Bassan, “Manufacturing the Future: 10 Trends To Come In 3D Printing,” *Forbes*, last modified December 7, 2012 <http://www.forbes.com/sites/ciocentral/2012/12/07/manufacturing-the-future-10-trends-to-come-in-3d-printing/>.

The tone of this report, and others like it, suggests that 3D printing has already made the leap from an emerging technology to a transformative one. Rather than focusing on the advanced use of these technologies, such as military and aerospace projects, these reports often cite uses of the technology for more common applications, such as tools, shoes, and children's toys, attempting to convince the reader of the ease with which popular products are made.⁴¹ Other authors, who also see a massive global expansion for the industry, focus their attention on the more advanced uses of the technology, such as the national defense and health and medical fields. These predictions are based on the speed at which the technology has evolved over the past five years, and include "self-healing" vehicles and aircraft made completely from a 3D printer.⁴²

These examples represent a set of opinions from sources that predict a bright future for 3D printing and often disregard the technology's current limitations. There are more conservative opinions that highlight the inherent weaknesses of 3D printing as it currently exists. Factors such as cost, complexity, and price overshadow the future possibilities and global diffusion. Arguments suggest these three elements alone could limit the technology's applicability to large corporations dealing with very complex modeling or the random hobbyist with a specific interest in 3D printing.⁴³

When examining sources of information on 3D printing, it is easy to classify most sources into three distinct categories. In the first category are those individuals and organizations that predict a 3D printing global diffusion—a world in which every household will be using 3D printers to fabricate items they need on a daily basis.⁴⁴ The second category focuses on the current limitations of the technology and predicts a much more limited future for the industry. In the third category are the groups that recognize the future potential of the technology but do not discount its current technological

⁴¹ Vivek Srinivasa and Jarrod Bassan, 2012.

⁴² William Koff and Paul Gustafson, *3D Printing and the Future of Manufacturing* (Falls Church, VA: CSC, 2012).

⁴³ Allen, "Why 3D Printing Is Overhyped."

⁴⁴ Hague and Reeves, "Additive Manufacturing and 3D Printing."

limitations. This middle-ground category is where most sources outside of popular media reports tend to be positioned.

1. Potential Legal Implications

Compared to other aspects of this review, the amount of available information on additive manufacturing's legal implications is somewhat limited. This is primarily because the technology, while nearly 30 years old, has only recently been affordable for the average consumer. Now that average consumers can afford some of the more basic technology, lawmakers must begin to understand its international legal implications. Sources cover a variety of these legal implications, but two central themes emerge:

- **Intellectual property rights**—3D printing and supporting tools allow almost anyone to intentionally or unintentionally recreate an existing product design, distribute that design, and manufacture the product, causing the manufacturer to lose out on significant investment in design, manufacturing, and marketing.⁴⁵
- **Undetectable Firearms Act**—The original law passed in the United States in 1988 makes it illegal for anyone to manufacture, import, sell, ship, deliver, possess, transfer, or receive any firearm that is not detectable by an airport metal detector. The law was extended again in 2013 but many are saying that the law alone is no longer enough, given the impact of 3D printing technologies.⁴⁶

Despite the identified need for action, sources indicate that progress has been stalled in many cases by partisan politics. In 2013, the federal government again extended the Undetectable Firearms Act, but any additional discussion on the implications of 3D technology was ineffective; parties were split on appropriate approaches to address these concerns.⁴⁷ While most sources avoid specific legal recommendations, they agree that these concerns must be considered now. As for any new area of technology, there may well be challenges while the legal frameworks catch up with the rate of technological

⁴⁵ Koff and Gustafson, *3D Printing and the Future of Manufacturing*.

⁴⁶ Richard Brown, "The Undetectable Firearms Act and 3D Printed Guns (FAQ)," CNET.com, last modified December 10, 2012, <http://www.cnet.com/news/the-undetectable-firearms-act-and-3d-printed-guns-faq/>.

⁴⁷ Brown, "The Undetectable Firearms Act."

change. Debating and developing legislation and regulation at an early stage will be important to make the most of the technology's benefits.⁴⁸

2. National and Homeland Security Implications

Sources addressing additive manufacturing, especially 3D printing, in the field of national and homeland security are also somewhat scarce. Most material simply highlights the advancements the military has either achieved or continues to research, such as the 3D printing of parts for military vehicles, bombs, food, and even skin.⁴⁹ Innovations such as these would have a significant effect on national security, but few sources go beyond discussing the actual products. One exception is the Strategic Foresight Report on 3D printing. It highlights four areas in which this technology could impact our national (and homeland) security:

- Weapons manufacturing could become easier—guns, bullets, bombs, and similar products could become cheaper and more easily accessible
- Weapons could be much more easily disguised (e.g., improvised explosive devices that look identical to non-weapons)
- Terrorists could lose their dependency on developed countries for their supplies
- Implications will also exist for counterfeiting⁵⁰

Somewhat vague in its presentation, the report highlights some of the potential impacts that 3D printing could have on the national security of the United States, but falls short of proposing possible solutions to these areas of concern.

Sources focused on homeland security issues are primarily concerned with the possibility of individuals printing their own personal firearms undetectable by normal security measures. Most of the information contained within these sources can be traced back to claims made by Defense Distributed, a company whose stated aim is to disrupt

⁴⁸ Hague and Reeves, "Additive Manufacturing and 3D Printing."

⁴⁹ Zachary Davies Boren, "US Army to use 3D printing for food, bombs, everything," *Independent*, last updated September 8, 2014, <http://www.independent.co.uk/life-style/gadgets-and-tech/us-army-to-use-3d-printing-for-food-bombs-everything-9643721.html>.

⁵⁰ Campbell, Williams, Ivanova, and Garrett, *Could 3D Printing Change the World?*.

the concept and mechanism of firearms regulation via 3D printed technology.⁵¹ While many sources use this company's claims as a rallying cry for regulation, it is apparent that very few of these sources understand what Defense Distributed has actually been able to accomplish at this point—or they present information in a way that intentionally evokes a response from a given audience. Furthermore, of the few sources mentioning the current laws and regulations already in place to prevent this very scenario, most sources only reference laws as a backdrop for how they can be exploited.⁵² There is a clear gap in available, unbiased sources examining the implications of this technology for homeland security.

C. SUMMARY

As previously noted, the first hurdle when examining sources of information on additive manufacturing and 3D printing is understanding the varied terminology. Because authors often mistakenly use related terms interchangeably, it takes extra effort to decipher the author's writing and fully appreciate central arguments and claims. The level of ambiguity also makes several sources simply unusable in the absence of further clarification.

The spectrum for describing additive manufacturing's current capabilities and future implications remains broad. With that said, sources generally agree about the potential for continued advancement for both complex and capable 3D systems and lower-end 3D printers. Even with the costs continuing to drop, however, there remain too many barriers—such as complexity and fabrication time—to think people will start replacing cheap items around the home with 3D printed products. As William Koff and Paul Gustafson note, “Although it is hard to predict where 3D printing at home will lead, it is safe to bet that consumers won't use these printers to recreate what they can already

⁵¹ Defense Distributed, last updated August 2014, <https://defdist.org/>

⁵² Joshua Kopstein, “Guns Want to be Free: What Happens When 3D Printing and Crypto-anarchy Collide,” *The Verge*, last modified April 12, 2013, <http://www.theverge.com/2013/4/12/4209364/guns-want-to-be-free-what-happens-when-3d-printing-and-crypto-anarchy>.

buy in stores.”⁵³ The reduction in costs could lead to more hobbyists and individuals experimenting with the devices, but the true impact is still unknown.

The primary focus of available information on additive manufacturing’s potential impact on the legal system, especially in the United States, is copyright issues and illegal firearms (undetectable and untraceable). While, at present, many of these considerations have stalled at the federal legislative level, there is a noticeable gap in source material from academic institutions examining these proposals. Many of the available sources included in this review have a vested interest in copyright protection issues and, as such, contain inherent biases dictated by their particular positions on a given issue. As noted, what is clear is that the legal system is lagging behind the advancements currently being made in this industry.

Trustworthy, unbiased sources addressing potential national and homeland security issues are also limited. It is possible that many of these issues have not been addressed simply because the future of the technologies and industry is unpredictable. Several sources suggest the additive manufacturing technology currently available to the private individual (the low-end 3D printer) is simply not advanced enough to cause any real concern for homeland security practitioners. Issues that have surfaced on the federal radar, such as gun control, consistently end up falling prey to partisan politics with very little movement toward meaningful action. As additive manufacturing technology continues to spread to a wider audience, homeland security practitioners will no doubt be forced to consider its potential implications, despite the absence of federal or state legislation.

⁵³ Koff and Gustafson, *3D Printing and the Future of Manufacturing*.

III. EMERGING TECHNOLOGY

At first glance, the worlds of emerging technology and public policy seem incompatible. After all, emerging technology is considered cutting edge, extremely dynamic, and visionary, while the common perception of government is that of a slow, bureaucratic, and reactionary machine. Gerald R. Faulhaber, a professor at the Wharton School of the University of Pennsylvania, notes, “If anything, governments are perceived by many to be a problem, not a solution, to the enhancement of a nation’s technological capabilities, with its power to tax, regulate, and otherwise burden innovation at every turn.”⁵⁴ This is a consistent theme in many arguments focused on the government’s role in deciding the future of additive manufacturing technology and practices. Many view any government involvement (usually expressed in the form of regulation) as a barrier to future innovation; but how accurate is this perception?⁵⁵ There are certainly examples to support this view—the seemingly unprepared government attempting to hastily shut down or seriously limit unexpected technologies via overregulation. The rise of Napster and the rapid proliferation of peer-to-peer sites are good examples of not only reactionary legislation to an unforeseen technology, but also the futility of such regulation.⁵⁶ For the first time, peer-to-peer technology enabled users with Internet connections and the installed computer application to instantly share files (both personal or fair use files, and those protected by copyright) without having to go through a centralized server (see Figure 1).⁵⁷

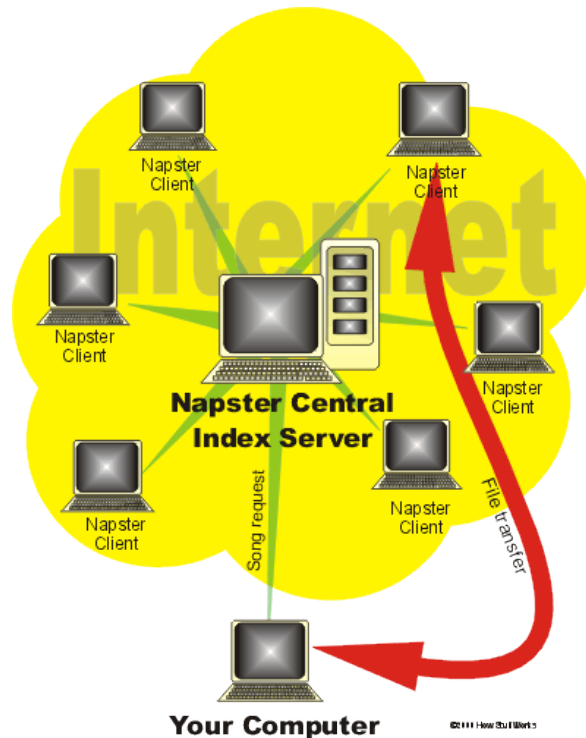
⁵⁴ Gerald R. Faulhaber, *Emerging Technologies and Public Policy: Lessons Learned from the Internet*, University of Pennsylvania, February 1999.

⁵⁵ Signe Brewster, “Can 3D Printing Avoid a Napster Moment?,” Gigaom, September 18, 2013, <https://gigaom.com/2013/09/18/can-3d-printing-avoid-a-napster-moment/>.

⁵⁶ Corey Rayburn, “After Napster,” *Virginia Journal of Law and Technology* 6, no. 3 (Fall 2001), <http://www.vjolt.net/vol6/issue3/v6i3-a16-Rayburn.html>

⁵⁷ Jeff Tyson, “How the Old Napster Worked,” October 30, 2000, HowStuffWorks, <http://computer.howstuffworks.com/napster.htm>.

Figure 1. Napster Central Index Server



From Tyson, Jeff. "How the Old Napster Worked." October 30, 2000. How Stuff Works.
<http://computer.howstuffworks.com/napster.htm>.

While opponents claimed this technology was a clear infringement on the existing copyright laws, users often cited the Audio Home Recording Act of 1992, which protected the sharing of digital recordings not intended for commercial use.⁵⁸ Clearly, the peer-to-peer technology had caught policymakers off-guard; it took years for legislation to address issues raised by this technology.⁵⁹ While the legislation slowly came together, the impact of piracy on the U.S. economy was estimated at \$10 billion annually.⁶⁰ How much could have been saved if policymakers understood peer-to-peer technology prior to Napster's launch? Other, more recent examples still playing out in the legislative arena

⁵⁸ Audio Home Recording Act, Title 17, Chapter 10, of the U.S. Code, October 28, 1992.

⁵⁹ Jeff Tyson, 2000.

⁶⁰ Steven E. Siwek, "The True Cost of Sound Recording Piracy on the U.S. Economy," Institute for Policy Innovation Center for Technology Freedom, October 3, 2007, http://ipi.org/ipi_issues/detail/the-true-cost-of-copyright-industry-piracy-to-the-us-economy.

are Bitcoin, the crypto-currency, and Uber, the electronic, cashless taxi service.⁶¹ These technologies are not only unexpected, they are also threatening to disrupt powerful industries. In several cases, these threatened industries have leveraged their political influence to limit or even eliminate these technologies before they can gain much traction.⁶² At the same time, the increased adoption rate and popularity of these new technologies suggests legislative bodies must address these emerging technologies in a measured and educated manner or face the prospect of an unhappy constituency.

Countering these examples, however, are cases in which government interest, direct involvement, and investment actually paved the way for innovation. It was the research and funding led by the Department of Defense's Advanced Research Projects Agency (ARPA) in the 1960s that created the groundwork for what became the World Wide Web (now more commonly referred to as the Internet).⁶³ While Apple takes much of the credit for their innovative iPhones and iPads, it was government funding that helped create many of those devices' individual components. Mariana Mazzucato has been making a name for herself discussing government involvement in innovation via her TED talks. Mazzucato notes, "Each of [the iPhone's] core technologies—capacitive sensors, solid-state memory, the click wheel, GPS, Internet, cellular communications, Siri, microchips, touchscreen—came from research efforts and funding support of the U.S. government and military."⁶⁴ As is the case with most arguments, the truth about government and public policy's effect on emerging technology, if there could ever be such a thing, lies somewhere between the extremes.

To better understand the arguments that exist between these extreme views, one must first understand the multiple ways in which a government can determine an

⁶¹ Dan Steinhart, "Bitcoin is the New Napster....And That Is a Good Thing," The Casey Report, August 28, 2013, <https://www.caseyresearch.com/articles/bitcoin-is-the-new-napster-and-thats-a-good-thing>.

⁶² Jared Meyer, "Paris Uber Protests: It's the Government vs. the Consumer and it's not Just in France," Fox News, June 25, 2015, <http://www.foxnews.com/opinion/2015/06/25/paris-uber-protests-its-government-vs-consumer-and-not-just-in-france.html>.

⁶³ Faulhaber, *Emerging Technologies and Public Policy*.

⁶⁴ Bruce Upbin, "Debunking the Narrative of Silicon Valley's Innovative Might," *Forbes*, June 13, 2013, <http://www.forbes.com/sites/bruceupbin/2013/06/13/debunking-the-narrative-of-silicon-valleys-innovation-might/>.

emerging technology's trajectory beyond the limiting aspects of regulation. In examining the government's role in creating and developing the Internet, Faulhaber identified five distinct models for government involvement in innovation. To Faulhaber, these models represent the full spectrum of government involvement in innovation, and the list ranks this involvement by increasing level of public intervention.

1. **Institutional Infrastructure**—governments provide legal frameworks and public institutions that encourage or discourage innovation
2. **Research Infrastructure**—governments invest in basic research (physics, electronics, microbiology, software, and other fundamental disciplines) and encourage the results to be widely disseminated by scholarly publication
3. **Military Technology**—direct government funding for defense-related technologies, particularly aviation/space and electronics/communications
4. **Government Directives**—a more interventionist model, in which governments take a direct role in encouraging or protecting the commercial exploitation of well-understood technologies, but do not directly fund it
5. **Government Subsidies**—perhaps the most interventionist model, in which governments explicitly attempt to “pick winners,” providing monetary support to specific organizations⁶⁵

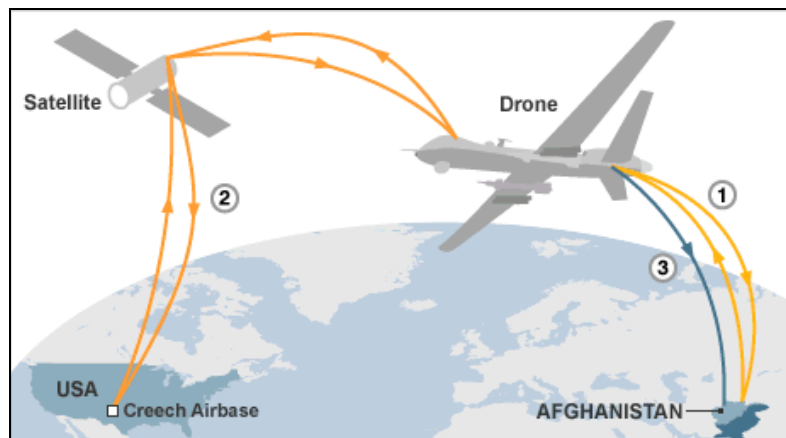
These five models illustrate that government involvement in innovation and emerging technology can go well beyond mere regulation. Each emerging technology discussed in this thesis has had varying levels of government involvement during initial development and evolution, as well as continued policy considerations. Until they made their way into the private sector over the last decade, unmanned aerial systems (UAS) were developed almost exclusively by the military. Conversely, autonomous vehicle technology has grown primarily from the private sector. Outside of a few examples, which will be discussed later in this paper, the U.S. military has invested comparatively little funding into the continued development of autonomous vehicle technology, especially when compared to its investments in UAS technology. These varied levels of government involvement have directly impacted the technologies' paths, but not always

⁶⁵ Faulhaber, *Emerging Technologies and Public Policy*.

predictably. Identifying lessons learned from the successes and failures of these technologies to current issues with additive manufacturing can help policymakers avoid the surprise and related pitfalls when attempting to address the future of additive manufacturing in the United States.

At its core, a UAS requires three elements: an operator, a vehicle, and a satellite (see Figure 2).⁶⁶ The operator is responsible for the initial launch of the vehicle. Once in flight, however, operators can either continue to remotely pilot the vehicle manually, or the vehicle could simply follow a pre-programmed flight path using an onboard geospatial positioning system (GPS). Either method of flight requires information from the vehicle to be collected by onboard cameras and other sensors, and then transmitted via satellite back to the original launch site for continued control.⁶⁷ While transmitting information back to its launch base, the vehicle can also interact with other elements in the field, such as field-deployed ground troops. As the next section of this paper illustrates, this real-time data has become increasingly valuable to the U.S. military in particular.⁶⁸

Figure 2. Unmanned Aerial System



From Drone Justice. "How a Drone Works." Accessed July 3, 2015, <http://dronejustice.com/what-is-a-uas/how-a-drone-works/>.

⁶⁶ "Unmanned Aerial Vehicle," U.S. Department of Defense, accessed July 7, 2015, <http://www.defense.gov/specials/uav2002/>.

⁶⁷ Ibid.

⁶⁸ Ibid.

A. HISTORICAL CONTEXT AND FUTURE APPLICATIONS

As is the case with most technologies, the most complex UASs today have roots in a much simpler technology. While looking nothing like its successors, many experts tend to agree that the first use of something resembling a UAS was in the mid-1800s.⁶⁹ On August 22, 1849, 200 pilotless balloons were outfitted with bombs and launched in an attack against the city of Venice.⁷⁰ Expanding their use in the United States Civil War, both the Union and Confederate armies used unmanned balloons for limited bombing operations.⁷¹ During the Spanish-American War, the U.S. military attached a camera to a kite, creating the first aerial surveillance pictures.⁷² For further advancements in the use of unmanned aerial systems beyond mere mechanical means to occur, developments in other technologies, such as radio technology, had to first be realized.

Moving beyond its very distant mechanical relatives, the first use of electronic UASs can be traced back to World War I (WWI), when both the British and U.S. militaries experimented with aerial torpedoes and flying bombs in an effort to destroy German U-boat facilities.⁷³ One such example developed by the U.S. Army in early 1918 was named “Kettering Bug” after its designer, Charles Kettering. The Bug, weighing in at a little over 500 pounds, was designed to launch mechanically via a ramp and pulley system; once in flight, however, it was controlled through a series of vacuum and

⁶⁹ For the purpose of this paper, the term “unmanned aerial system” is used synonymously with unmanned aerial vehicle (UAV) and unmanned combat aerial vehicle (UCAV). While the use of the UAV acronym is more popular in mass media and academia, the Department of Defense recognizes the use of UAS when referring to unmanned aerial technology. Also commonly associated with this type of technology is the use of the word “drone.” Given the evolution of the technologies and the historical use of the word, DOD does not recognize this term when referring to the more complex unmanned aerial technologies currently in existence. To reduce confusion to the reader, this author avoids using the term drone outside of direct quotations unless referring to the simpler commercial and consumer unmanned aerial technology. For more information regarding DOD’s use of the terminology, see John Keller, “Drone, UAV, UAS ... What Do We Call that Unmanned Flyin’ Thing, Anyway?” *Military and Aerospace*, accessed, June 6, 2015, <http://www.militaryaerospace.com/blogs/mil-aero-blog/2011/11/drone-uav-uas-what-do-we-call-that-unmanned-flyin-thing-anyway.html>.

⁷⁰ Ian G. R. Shaw, “The Rise of the Predator Empire: Tracing the History of U.S. Drones,” *Understanding Empire*, 2014, <https://understandingempire.wordpress.com/2-0-a-brief-history-of-u-s-drones/>.

⁷¹ Ibid.

⁷² Ibid.

⁷³ John F. Keane and Stephen S. Carr, “A Brief History of the Unmanned Aircraft,” *Johns Hopkins APL Technical Digest* 32, no. 3 (2013).

electrical systems.⁷⁴ October 22, 1918 marked the Bug's first successful flight. Thus, only 15 years after the advent of manned flight, a device completely controlled via remote operators successfully dropped an explosive payload on an intended target.⁷⁵ Although, due to the number of failed attempts, a deployable version of the technology was not completed prior to the end of hostilities, these early developments would pave the way for much more advanced systems following the war.⁷⁶

Following WWI, the U.S. military's interest in unmanned flight diminished significantly as the nation instead focused on the continued development of its national air management system. This investment included the development and deployment of navigation aids, airdromes, weather stations, and control centers intended to make long-distance overland flight safer and more regular.⁷⁷ While significantly diminished, the military's interest in unmanned aerial system technology did not disappear altogether. The years between WWI and WWII saw continued advancements in radio and television technology that would quickly find their way into UASs of the time.

Operation Aphrodite was a secret United States Air Force operation designed to not only deliver a devastating explosive payload against enemy targets, but also to dispose of B-17s that were of no further use to the military.⁷⁸ B-17s designated for these missions were first stripped of all their normal armament and then loaded with as much explosive ordinance as possible. They were then outfitted with radio remote control systems that used television cameras for targeting purposes. Following a manually piloted liftoff, the pilots would bail out to safety and control would be given to a "mothership" trailing the aircraft at a distance of up to six miles.⁷⁹ Contrary to military leaders' expectations, Operation Aphrodite was far from successful. Of the eight missions flown,

⁷⁴ Ibid.

⁷⁵ Shaw, "The Rise of the Predator Empire."

⁷⁶ Richard M. Clark, *Uninhabited Combat Aerial Vehicles: Airpower by the People, for the People, but not with the People* (CADRE Paper No. 8) (Maxwell Air Force Base, Montgomery, Alabama: Air University Press, 2000).

⁷⁷ Keane and Carr, "A Brief History of the Unmanned Aircraft."

⁷⁸ Ibid.

⁷⁹ Ibid.

only one landed close enough to its intended target to cause any significant damage. Several planes crashed prematurely, and one even landed safely in enemy territory, gifting the Germans a perfectly intact B-17.⁸⁰

Following the end of WWII, a significant shift occurred in the continued use and development of UASs. The Cold War and the Vietnam War necessitated the development of UASs that could gather intelligence in areas far removed from combat. This meant new UASs had to be designed to remain in flight for extended durations and equipped with technology that would enhance their intelligence-gathering capabilities.⁸¹ Advancements in UAS photographic technology often met or exceeded the militaristic requirements and expectations at the time.⁸² So successful was the implementation of new technology into UASs that, during the Vietnam War, from 1964–1975, over 1,000 UASs flew over 34,000 reconnaissance and surveillance missions across Southeast Asia.⁸³ The central drawback of the increased UAS use during this period was the length of time these devices could remain in the air, maxing out at around 120–180 minutes.⁸⁴ Despite these limitations, these devices saved lives; pilots were no longer required to personally fly in dangerous airspace for most reconnaissance missions.

Military interest in UASs once again waned following the conclusion of the Vietnam War. The combination of drastic cuts in military spending and increased interest in high-speed missile systems, long-range bombers, and cruise missiles meant that advancements in UASs were virtually non-existent for nearly a decade.⁸⁵ The Persian Gulf War in 1990 and 1991 once again drew a renewed interest in UASs from the military. But with the conflict lasting less than a year, UASs did not see much action. Frustrated with the lack of progress, Congress banned the Defense Advanced Research Projects Agency (DARPA) from further UAS research and essentially forced the

⁸⁰ Ibid.

⁸¹ Shaw, “The Rise of the Predator Empire.”

⁸² Keane and Carr, “A Brief History of the Unmanned Aircraft.”

⁸³ Shaw, “The Rise of the Predator Empire.”

⁸⁴ Ibid.

⁸⁵ Keane and Carr, “A Brief History of the Unmanned Aircraft.”

Pentagon to house the program in an office not funded for research.⁸⁶ When yet another international conflict broke out in the former Yugoslavia requiring immediate intelligence, the Central Intelligence Agency (CIA) circumvented the Congressional block and acquired a number of UASs for intelligence-gathering purposes.⁸⁷ Improvements to UAS design in the early 1990s eventually led to the birth of the most recognizable UAS design today, the Predator. Like most of its predecessors, the Predator was primarily engaged in intelligence-related operations. Following the events of September 11, 2001, however, the CIA and subsequently the U.S. military quickly went to work arming the Predator for targeted killing operations supporting the Global War on Terror (GWOT).⁸⁸ Because of the Predator's high-profile involvement in the GWOT and resulting frequency of its appearances in popular media over the last decade, any mention of drone technology is usually associated with the weaponized version of this model UAS.⁸⁹ This association with the weaponized Predator has been identified as one reason Americans tend to support the continued use of drones overseas in military operations (drone strikes), but do not want them used domestically by law enforcement agencies or private sector companies such as Amazon.⁹⁰

Often neglected in popular media, but gaining popularity and momentum in the global marketplace over the past five years, however, is the commercial and consumer side of UAS technology.⁹¹ With a much shorter and certainly less storied history than their military counterparts, commercial and consumer UASs only started appearing in the

⁸⁶ Shaw, "The Rise of the Predator Empire."

⁸⁷ Chris Woods, "The Story of America's First Drone Strike," *Atlantic*, May 30, 2015, <http://www.theatlantic.com/international/archive/2015/05/america-first-drone-strike-afghanistan/394463/>.

⁸⁸ Ibid.

⁸⁹ Daniel Terdiman, "The History of the Predator: The Drone that Changed the World (Q&A)," CNET, September 20, 2014, <http://www.cnet.com/news/the-history-of-the-predator-the-drone-that-changed-the-world-q-a/>.

⁹⁰ Bruce Drake, "Report Questions Drone Use, Widely Unpopular Globally, but not in the U.S.," Pew Research Center, October, 23, 2013, <http://www.pewresearch.org/fact-tank/2013/10/23/report-questions-drone-use-widely-unpopular-globally-but-not-in-the-u-s/>; "Voters are Gung-Ho for Use of Drones but not over the United States," Rasmussen Reports, February 13, 2012, http://www.rasmussenreports.com/public_content/politics/current_events/afghanistan/voters_are_gung_ho_for_use_of_drones_but_not_over_the_united_states.

⁹¹ Jeff Desjardins, "The Big Business of Drones," Visual Capitalist, August 21, 2014, <http://www.visualcapitalist.com/big-business-consumer-drones/>.

last decade.⁹² Radio-controlled (RC) airplanes and helicopters had, in fact, been around for decades, but always relied on a human operator to control the apparatus in flight. Recent advancements in GPS technology enabled the new devices to not only be pre-programmed for flight without a human operator, but also made it affordable to the average hobbyist or regular consumer. A basic quadcopter with a mid-level camera can be purchased on Amazon for under \$100. Experts predict the combination of these two factors, the improvements in related UAS technology, and the low cost of entry into the market suggest demand for commercial and consumer UASs will only increase over the next decade.⁹³

B. DRIVERS FOR TECHNOLOGICAL MATURATION

As previously discussed, a significant driver in the ongoing development and increased capabilities of UASs has been related to military operations. Improvements in UASs were needed for faster and more reliable intelligence, more accurate target acquisition capabilities, and to simply enable the military to go places not humanly possible—such as the middle of a nuclear cloud to collect radiation samples following a nuclear detonation.⁹⁴ WWII provided yet another incentive for UAS enhancements. With a staggering 40,000 aircraft destroyed and over 80,000 crewmembers killed in that war alone, the move toward UASs was both humane and economical.⁹⁵ Those same motivations remain to this day as danger persists with conflicts in the Middle East and the U.S. military’s role in the ongoing GWOT.

Another driver for UAS maturation on the military side of the technology has the potential to impact the United States’ position in the global marketplace. As one of the few countries with highly sophisticated and weaponized UASs, the United States has

⁹² The distinction between remotely piloted UASs and radio-controlled aircraft, such as toy helicopters, is rather ambiguous as it is currently defined by the Federal Aviation Administration. Those definitions have been hotly contested by hobbyist groups such as the Academy of Model Aeronautics and a final decision has yet to be made. For the purposes of this paper, this author does not include radio-controlled aircraft (hobbyist) as part of the UAS industry.

⁹³ Desjardins, “The Big Business of Drones.”

⁹⁴ Department of Defense, *Unmanned Aircraft Systems Road Map 2005–2030* (Washington, DC: Department of Defense, 2005).

⁹⁵ Keane and Carr, “A Brief History of the Unmanned Aircraft.”

benefitted from relatively little competition in the manufacturing and distribution of these systems.⁹⁶ How long that lasts, however, remains to be seen. With countries such as China, Israel, Italy, and the United Kingdom developing their own UASs, some with weaponized capabilities, the competition to have the most sophisticated fleet is likely to pressure the United States for continuous enhancements.⁹⁷

The private sector is also exerting significant influence on the continued enhancement of UAS technology.⁹⁸ Global giants such as Amazon have not only expressed interest in using UASs for daily operations, but have already begun to invest their own resources into research and design (R&D) efforts. In a letter to the Federal Aviation Administration (FAA) Administrator, Vice President for Global Public Policy at Amazon, Paul Misener, outlined Amazon's future goal of implementing the program Amazon Prime Air. According to Misener, the objective of this program is to use UAS technology to deliver packages to a customer's door within 30 minutes of placing an order.⁹⁹ Misener's letter also highlights that Amazon's own R&D efforts have enabled them to design UASs to meet their company's specific needs; for example, an aerial vehicle that can travel over 50 miles per hour and safely carry a payload of up to five pounds.¹⁰⁰ Commercial efforts and investments such as these will continue to drive future UAS innovations.

Finally, an often-overlooked source of innovation, especially as it pertains to advanced technology, is the private individual. Commonly self-identified as "tinkerers," these are the people who obtain a technology and figure out ways to make it better, or better suited to their specific needs.¹⁰¹ From the earliest days of radio-controlled airplanes to the development of the Predator, tinkerers have played an important role in

⁹⁶ Kristin Roberts, "When the Whole World Has Drones," *National Journal Magazine*, March 21, 2013, <http://www.nationaljournal.com/magazine/when-the-whole-world-has-drones-20130321>.

⁹⁷ Ibid.

⁹⁸ Alex Ashworth, "Rise of the Commercial Drone," BlueFetch, June, 1, 2015, <http://bluefletch.com/blog/rise-of-the-commercial-drone/>.

⁹⁹ Amazon Letter, July 9, 2014.

¹⁰⁰ Ibid.

¹⁰¹ Mark Hatch, *The Maker Movement Manifesto* (New York: McGraw Hill, 2014).

UAS innovation.¹⁰² That role is no less important today, especially now that cheaper technology is available to a broader audience. The DJI Phantom Aerial Drone Quadcopter, currently retailing for around \$500, started out as one person's simple idea to attach a GoPro camera to a small UAS.¹⁰³ In fact, DJI, which is about to become a billion-dollar company focused on UASs, was launched in 2006 by Frank Wang while he was a student at the Hong Kong University of Science and Technology.¹⁰⁴ At the time, most consumer drones were focused on the serious hobbyist and required a certain level of experience to construct and fly. Recognizing the opportunity, Wang directed his company into developing simple, easy-to-use, but comparably capable UASs, and his success is now global.¹⁰⁵ As more tinkerers like Wang obtain these technologies, there is no way to accurately predict the origin of the next big idea or the industry's trajectory in general. As the next section illustrates, this industry's unpredictability also hampers the development of informed public policy.

C. PUBLIC POLICY

To describe the current environment succinctly, public policy on domestic UAS use in the United States is currently under intense debate. This debate includes civilian, commercial, law-enforcement, and other public use. The FAA is charged with the safety and security of the nation's airspace and, as such, has been tasked by Congress (via the FAA Modernization Act of 2012) to develop appropriate policies for the safe integration of UASs into the National Airspace by September 30, 2015.¹⁰⁶ The Department of Transportation's (DOT) Assistant Inspector General, Matthew Hampton, testified before

¹⁰² Richard Whittle, "The Man Who Invented the Predator," *Smithsonian Air and Space*, April 2013, <http://www.airspacemag.com/flight-today/the-man-who-invented-the-predator-3970502/?no-ist>.

¹⁰³ Ben Popper, "DJI is about to Become the First Billion Dollar Consumer Drone Company," *The Verge*, March 12, 2015, <http://www.theverge.com/2015/3/12/8196413/dji-drone-funding-billion-dollar-sales>.

¹⁰⁴ *Ibid.*

¹⁰⁵ *Ibid.*

¹⁰⁶ "Unmanned Aircraft Systems," Federal Aviation Administration, February 11, 2015, accessed June 7, 2015, https://www.faa.gov/uas/media/Sec_331_336_UAS.pdf.

Congress that DOT will not complete the assigned provisions by that deadline.¹⁰⁷ According to Hampton, of the 17 assigned provisions involving the integration of UASs into the National Airspace, only nine will be completed by the September deadline.¹⁰⁸

The FAA's inability to establish a regulatory framework for UAS integration in the national airspace has not prevented their use. It has, however, created an environment in which public sector entities such as law enforcement agencies and emergency management agencies, private sector companies, and individual civilians are all operating UASs with little to no formal federal guidelines. In absence of federal guidelines, several organizations established their own. As far back as 2012, the International Association of Chiefs of Police (IACP) was considering the potential implications of this technology and issued their own guidelines on the use of drones for law enforcement related operations.¹⁰⁹ While IACP was applauded for their efforts and forward thinking, their guidelines focused almost exclusively on privacy issues and did little to address the safe integration of UASs into the national airspace.¹¹⁰ While the IACP and other organizations developed basic guidelines and recommendations, none of those proposals had the actual weight of law. This created confusion for both the operators and the general public, which still exists today.¹¹¹ As a result, the public's confidence in the government's ability to adequately address UAS issues has been shaken and, more importantly, has created potentially dangerous situations in the field.

In September 2013, Chris Miser, the owner of Falcon UAV, was working with Colorado Emergency Management Agency personnel during a flooding event outside of Boulder, Colorado. Miser was sharing data one of his drones captured from a town that

¹⁰⁷ Matthew E. Hampton, "FAA's Progress and Challenges Integrating Unmanned Aircraft Systems into the National Airspace System," Congressional Testimony.

¹⁰⁸ Ibid.

¹⁰⁹ "Recommended Guidelines for the use of Unmanned Aircraft," International Association of Chiefs of Police Aviation Committee, August 2012, http://www.theiacp.org/portals/0/pdfs/IACP_UAGuidelines.pdf.

¹¹⁰ Jay Stanley, "Police Chiefs Issue Recommendations on Drones; A Look at how They Measure Up," ACLU, August 7, 2012, <https://www.aclu.org/blog/police-chiefs-issue-recommendations-drones-look-how-they-measure>.

¹¹¹ Ibid.

had been directly impacted by floodwaters when, after receiving approval from his local contacts, he prepared to send another drone out to capture similar data in a neighboring town. According to Miser, prior to launching his second drone, he was called once again by one of his local contacts at the emergency operations center (EOC) and was told that the Federal Emergency Management Agency (FEMA) “was in control of the airspace and that if his drone took off, he would be arrested.”¹¹² The fact that FEMA does not have arresting authorities notwithstanding, confusion over the use of UASs in controlled airspace could have been disastrous in this particular case. Civil Air Patrol and the National Guard routinely send their own air assets into the airspace surrounding disaster locations for damage assessments and search and rescue operations, and those flights have to be closely coordinated with the Federal Coordination Official (FCO) and the FAA to avoid possible accidents.¹¹³ A private sector company attempting to assist response operations may have good intentions, but without proper policies and protocols in place it has the potential to cause more harm than good. These types of scenarios will only continue until FAA is able to establish policies to which commercial UAS operators can adhere.

UAS policy issues surrounding emergency management and law enforcement agencies tend to receive a lot of attention in the media, as they should. The implications of public-entity UAS use have the potential to impact the very interpretations of our Constitution and the notions set forth by the Fourth Amendment.¹¹⁴ While these debates rage on, however, another issue has both literally and figuratively flown under the radar. This often-overlooked policy deficiency pertains to the use of what the FAA classifies as

¹¹² John Galvin, “Officials Halt Drone Operator Trying to Aid Colorado Responders,” *Popular Mechanics*, September 17, 2013, <http://www.popularmechanics.com/adventure/outdoors/a9466/officials-shut-down-drone-operator-trying-to-aid-colorado-rescuers-15936242/>.

¹¹³ Department of Homeland Security, *National Response Framework* (Second Edition) (Washington, DC: Department of Homeland Security, 2013).

¹¹⁴ Bennett C. Wells, “Civilian Drones, Privacy, and the Federal-State Balance,” *The Brookings Institution*, September 2014, <http://www.brookings.edu/research/reports2/2014/09/civilian-drones-and-privacy>.

model aircraft.¹¹⁵ While on the surface this issue may not appear to be as critical as others, recent events have showcased the danger UASs pose to commercial airliners.

On March 29, 2015, Shuttle America Flight 2708 was making its final approach toward a runway at LaGuardia Airport when the flight's pilot was forced to quickly ascend 200 feet to avoid hitting a drone. The flight crew reported the unmanned aircraft was flying at an altitude of about 2,700 feet at the time.¹¹⁶ This is but one of hundreds of FAA incident reports in the last year alone describing scenarios in which commercial airliners nearly collided with UASs.¹¹⁷ These concerns are not unique to the United States. On April 20, 2015, a UAS spotted at Manchester Airport in the United Kingdom grounded flights for 20 minutes and forced several other flights to be diverted elsewhere.¹¹⁸ Explaining the danger of these drones to aircraft, Jim Williams, head of FAA's UAS office, noted, "Imagine a metal and plastic object—especially one with a big lithium battery—going into a high-speed engine. The results could be catastrophic."¹¹⁹

Williams goes on to note that the complexity of integrating such technology into the national airspace is no simple task. While this is certainly true, the fact remains that the FAA essentially did nothing to update its policy for radio-controlled aircraft for over 25 years. Advisory Circular 91-57, issued in June 1981, provides little more than voluntary safety guidelines for model aircraft operators. The only specific requirements outlined in the document are for operators to keep their models below 400 feet and to

¹¹⁵ This author recognizes the importance of these debates' policy implications. Given the amount of attention already afforded these issues, however, this paper focuses on other, less popular topics. This will be noted in the "limitations of research" section of this paper as well.

¹¹⁶ Samantha Tata, "Plane Has Close Call with Drone Above Prospect Park: FAA," *Pix11*, May 29, 2015, <http://pix11.com/2015/05/29/plane-has-close-call-with-drone-above-prospect-park-faa/>.

¹¹⁷ Craig Whitlock, "Near-collisions Between Drones and Airliners Surge, New FAA Reports Show," *Washington Post*, November 26, 2014, http://www.washingtonpost.com/world/national-security/near-collisions-between-drones-airliners-surge-new-faa-reports-show/2014/11/26/9a8c1716-758c-11e4-bd1b-03009bd3e984_story.html.

¹¹⁸ "Drone Sighting at Manchester Airport Grounds Flights for 20 Minutes," *Manchester Evening News*, April 20, 2015, <http://www.manchestereveningnews.co.uk/news/greater-manchester-news/drone-sighting-manchester-airport-grounds-9081828>.

¹¹⁹ Greg Bothello, "FAA Official: Drone, Jetliner Nearly Collided over Florida," *CNN*, May 11, 2014, <http://www.cnn.com/2014/05/09/travel/unmanned-drone-danger/>.

notify the nearby traffic control tower if flying within three miles of an airport.¹²⁰ As the UAS technology around them drastically changed over the period of a quarter of a century, no one at FAA saw the need to update this policy.

Finally, recognizing the need to update this policy, the FAA has issued preliminary guidance and new UAS classifications while the FAA Modernization and Reform Act of 2012 is under revision. Unfortunately, the new classifications are ambiguous at best and the draft policies are potentially dangerous. Under the proposed policy, commercial and public sector entities must apply for a certificate to operate prior to their actual flights, as long as the device is used for recreational or hobby purposes and is under 55 pounds in total weight; civilians, however, do not have to apply for the same certificate.¹²¹ Furthermore, given the specific language on the site itself, the degree to which these guidelines will be enforced is questionable. According to the FAA website, “Individuals flying for hobby or recreation are strongly encouraged to follow safety guidelines.”¹²² The current language in the proposed rules suggests operators in the commercial and public sectors, who would be expected to take some level of training prior to flying an apparatus owned by a company or organization, are subjected to more scrutiny from the FAA than untrained private operators.

As the sole agency tasked by Congress to identify and develop the quickest and safest, and legal ways forward, , the actions of the military, law enforcement community, private sector, and the private citizens are all applying considerable pressure on the FAA. Concurrently, individual states have begun to implement their own UAS policies. Since 2012, 45 states have considered over 150 separate bills related to the use of UASs.¹²³ Not surprisingly, these bills vary greatly in scope, complexity, and focus. Many bills focus on

¹²⁰ “Advanced Circular 91-57—Model Aircraft Operating Standards,” Federal Aviation Administration, June 9, 1981, https://www.faa.gov/regulations_policies/advisory_circulars/index.cfm/go/document.information/documentid/22425.

¹²¹ “Model Aircraft Operations,” Federal Aviation Administration, accessed August 11, 2015, https://www.faa.gov/uas/model_aircraft/.

¹²² Ibid.

¹²³ National Conference of State Legislatures, Current Unmanned Aircraft State Law Landscape, June 30, 2015, <http://www.ncsl.org/research/transportation/current-unmanned-aircraft-state-law-landscape.aspx>.

specific law enforcement activities while others address a wider selection of issues.¹²⁴ Michigan SB 54 prohibits the use of a UAS to interfere or harass an individual who is hunting, while “Mississippi SB 2022 specifies that using a drone to commit ‘peeping tom’ activities is a felony.”¹²⁵ The entire collection of state legislation to date can be best described as a patchwork of related but very different pieces of regulation. This is to be expected when 50 separate entities try to individually address issues related to UASs—even more so when no federal legislation exists. This approach to UAS legislation is inefficient and confusing for private citizens and commercial companies desiring to operate a UAS legally, which is an approach that should be avoided when attempting to address concerns related to additive manufacturing.

D. SUMMARY

As this paper has illustrated, for almost a century, nearly every investment into the continued enhancement of UASs originated from a government; primarily for the purposes of supporting military operations. Despite this level of direct government involvement however, policymakers were seemingly unprepared for the technology’s leap into private sector markets. Now that the technology has become significantly less expensive and more widespread, policymakers must quickly develop a coherent strategy for the safe incorporation of UASs into the national airspace. Because this strategy does not currently exist, organizations with a vested interest in the use of UASs have attempted to independently address identified issues via their own policy development process (see Table 1 for summary). As the military, private sector, and private citizens continue to push the continued advancement of this technology, it is critical that UAS policy is strategically developed in a collaborative environment with impacted stakeholders.

¹²⁴ Allie Bohm, “Drone Legislation: What’s Being Proposed in the States,” ACLU, March 6, 2013, <https://www.aclu.org/blog/drone-legislation-whats-being-proposed-states>.

¹²⁵ National Conference of State Legislatures, 2015.

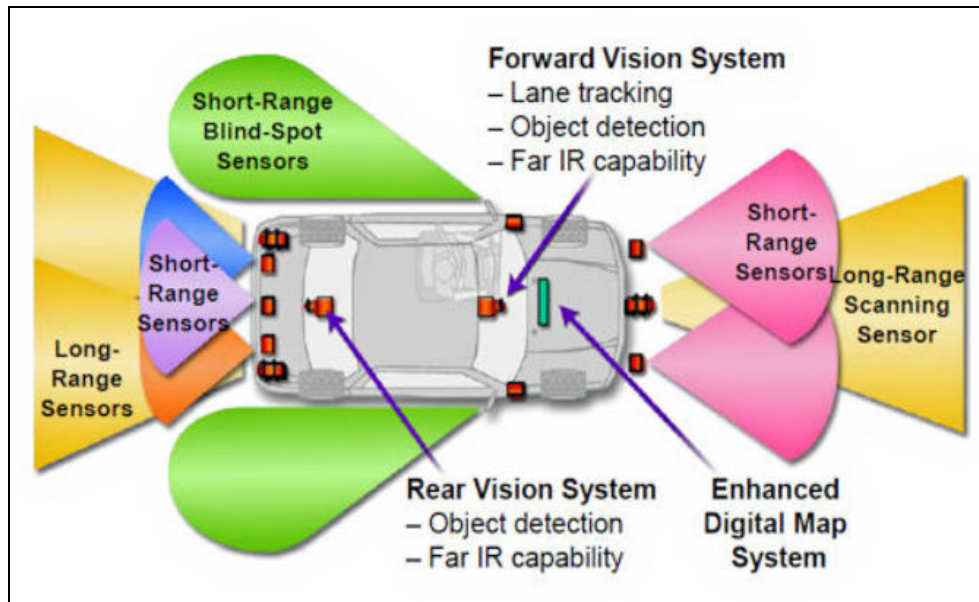
Table 1. Unmanned Aerial Systems Policy

UAS Policy Summary	
<i>Federal</i>	<ul style="list-style-type: none"> • <i>February 2015</i>—FAA issued a proposed rulemaking on the use of UASs to include new classifications and rules for commercial use. • Proposed rules must go through public comment process and could take up to two years to become fully implemented. • <i>April 2015</i>—FAA proposed a new framework of regulations for small UAS systems (under 55lbs). • <i>May 2015</i>—U.S. Department of Justice (DOJ) issues guidance for law enforcement agencies on the use of drones for surveillance • DOJ rules incorporate FAA regulations related to commercial use of drones
<i>State</i>	<ul style="list-style-type: none"> • <i>As of 2015</i>, 45 States have considered over 150 bills related to the use of UASs. • 25 states have enacted laws addressing UAS issues and another six states have adopted resolutions <ul style="list-style-type: none"> ○ Laws vary significantly from state to state
<i>Other</i>	<ul style="list-style-type: none"> • <i>August 2012</i>—International Association of Chiefs of Police (IACP) issues guidelines on the use of UAS in law enforcement related activities

IV. AUTONOMOUS VEHICLES

Sridhar Lakshamanan, a professor of engineering at the University of Michigan-Dearborn and an autonomous vehicle expert, notes there are three basic elements needed to convert a regular car into an automated vehicle: a GPS, a system of sensors to recognize the dynamic environment, and a computer to process the information and convert it into vehicle actions.¹²⁶ Simplified, the autonomous vehicle uses technology to simulate actions normally handled by the human brain. A myriad of sensors continuously interacts with the environment and send the data to a computer, which tells the vehicle to perform actions such as braking or changing lanes (see Figure 3). While it will be years before an autonomous vehicle is available for public use, the technology is improving enough to predict a safer roadway after widespread adoption.¹²⁷

Figure 3. Autonomous Vehicle Sensors



From Inquisitr. “Autonomous Vehicles Are the Wave of the Future, Says Stephen Diaco.” May 4, 2014. <http://www.inquisitr.com/1236826/autonomous-vehicles-are-the-wave-of-the-future-says-stephen-diaco/>.

¹²⁶ John Patrick Pullen, “You Asked: How to Driverless Cars Work?,” *Time*, February 24, 2015, <http://time.com/3719270/you-asked-how-do-driverless-cars-work/>.

¹²⁷ Ibid.

A. HISTORY

The desire to build a truly autonomous vehicle has been around since the invention of the automobile itself. But, as is the case throughout much of human history, technology had to catch up to turn mere dreams into a reality. Over the last century, inventors have quickly worked to integrate new technologies into the automobile. Early experiments in radio-controlled vehicles in the 1920s produced one of the first “driverless” cars, the *Linrrican Wonder*, but the requirement to have it operated via human control made it far from truly autonomous.¹²⁸ Other prototypes in the 1920s and 1930s simply demonstrated improvements in the use of radio technology to remotely pilot a driverless vehicle.

Constrained by the limits of radio technology and pre-dating the digital and computer ages, early inventors next looked for true autonomy outside of the vehicle itself. At the 1939 World’s Fair in New York, American designer and futurist Norman Bel Geddes introduced his vision in the Futurama ride: an autonomous system that relied not only on the technology inside the vehicle, but the interaction of that technology with sensors imbedded in the road.¹²⁹ Because much of the danger for drivers at the time was the road itself, often very narrow and poorly marked, Geddes’ concept suggested improvements to both the vehicle and the highway system in which it was intended to be used.¹³⁰ Possibly stimulated by the underlying concepts of the Futurama exhibit, the idea of an intelligent highway system quickly became the popular route to achieving a truly autonomous vehicle. In fact, those concepts became so popular that companies and inventors spent the next 40 years trying to perfect the interaction between the intelligent vehicle and the smart highway.

¹²⁸ Nickey Mouse, “History of Self-Driving Cars,” The WirelessBanana, January 6, 2014, <https://www.thewirelessbanana.com/news/history-of-self-driving-cars/>.

¹²⁹ Marc Weber, “Where To? A History of Auntomous Vehicles,” Computer History Museum, accessed June 20, 2015, <http://www.computerhistory.org/atcm/where-to-a-history-of-autonomous-vehicles/>.

¹³⁰ Ibid.

In 1956, General Motors (GM) introduced the *Firebird II*, a concept car guided by electronic sensors in the highway.¹³¹ In the late 1960s and into the 1970s, the Bendix Corporation also developed several driverless vehicle prototypes that interacted with cables buried next to the highway.¹³² At the same time, thousands of miles away, the Transport and Road Research Laboratory in the United Kingdom was testing similar ideas. A prototype Citroen DS19 successfully completed high-speed trial runs guided by a four-mile stretch of buried cable.¹³³ These trends continued throughout the 1960s and 1970s with increasing sophistication in highway automation technology. However, the significant cost of implementing these technologies on a national highway system ensured they would never become a reality.

It was not until the 1980s that the focus of the autonomous vehicle once again turned primarily to the vehicle itself—specifically to developing “both semi-autonomous and autonomous vehicles that depended little, if at all, on highway infrastructure.”¹³⁴ Advancements in visual and computer processing technology enabled researchers to integrate what was at the time considered to be rather sophisticated cameras and microprocessors into the driving functions of prototype automobiles. In one of the most famous examples of the advancements made in this arena at the time, a team led by German aerospace engineer Ernst Dickmanns outfitted a vehicle dubbed *VAMORS* with cameras, microprocessors, and other sensory equipment and successfully drove a course of roughly 12 miles at speeds of up to 56 miles per hour, without a human operator.¹³⁵ Eight years later, Dickmanns’ team piloted a Mercedes S-Class from Munich, Germany to Odense, Denmark. This trip, which totaled nearly 1,000 miles, was accomplished at varying speeds up to 112 miles per hour with, as Dickmanns noted, about 95% of the

¹³¹ Ian Bogost, “The Secret History of the Robot Car,” *Atlantic*, November 2014, <http://www.theatlantic.com/magazine/archive/2014/11/the-secret-history-of-the-robot-car/380791/>.

¹³² Roy Allen Cohen, “Self-Driving Technology and Autonomous Vehicles: A Whole New World for Potential Product Liability Discussion,” IADC Committee Newsletter, May, 2015, <http://www.pbnlaw.com/media/540169/Cohen-IADC-Product-Liability-May-2015.pdf>.

¹³³ John Reynolds, Cruising Into the Future, *The Telegraph*, May 26, 2001, <http://www.telegraph.co.uk/motoring/4750544/Cruising-into-the-future.html>.

¹³⁴ James A. Anderson et al., *Autonomous Vehicle Technology—A Guide for Policymakers* (Santa Monica, CA: RAND, 2014).

¹³⁵ *Ibid.*

distance traveled fully automatically.”¹³⁶ At roughly the same time, in the mid-1990s, Carnegie Mellon University robotics drove NavLab 5, a modified Pontiac Trans Sport, from Pittsburgh to Los Angeles. This trip’s “autonomous driving percentage” was rated at 98.2%, with human interaction occurring primarily through obstacle-avoidance scenarios.¹³⁷ The successful trials performed by these early, visually based guidance vehicles heavily influenced the direction of future research. Nearly all research and associated funding involving intelligent highways either ceased entirely or was redirected toward enhancing these new visually guided vehicles.¹³⁸

In the early 2000s, the U.S. military also began taking an interest in autonomous vehicles. In 2004, with an initial goal to have roughly 30% of its entire military vehicle fleet operating autonomously by 2015, the Defense Advanced Research Projects Administration (DARPA) set up a 150-mile off-road race, and invited dozens of autonomous-vehicle development teams to compete for multi-million-dollar prizes.¹³⁹ The first race was less than successful; no team completed more than eight miles of the race.¹⁴⁰ The next race conducted in the same environment a mere 18 months later, however, saw five teams successfully complete the race in roughly seven hours.¹⁴¹ In 2007, the final race funded by DARPA, dubbed *Urban Challenge*, required teams to successfully navigate a 60-mile urban course while obeying all traffic laws and operating alongside other vehicles. Six teams completed the course and three of those six managed to accomplish the feat in under five hours.¹⁴² Advancements in road-following and collision avoidance software, along with improved radar and laser sensors, made these monumental strides in the capabilities of autonomous vehicles possible in a relatively

¹³⁶ Tom Vanderbilt, “Autonomous Cars through the Ages,” *Wired*, February 6, 2012, <http://www.wired.com/2012/02/autonomous-vehicle-history/>.

¹³⁷ “Driverless Car,” Project Gutenberg Self-Publishing Press, accessed June 20, 2015, http://self.gutenberg.org/articles/Driverless_Car.

¹³⁸ Vanderbilt, “Autonomous Cars through the Ages.”

¹³⁹ Anderson et al., *Autonomous Vehicle Technology*.

¹⁴⁰ Weber, “Where To?.”

¹⁴¹ Anderson et al., *Autonomous Vehicle Technology*.

¹⁴² Ibid.

short amount of time.¹⁴³ It is clear today that the DARPA challenges did not accomplish the original goal of supplanting 30% of the U.S. military's fleet with autonomous vehicles by 2015. But what they did achieve was just as significant for the future of the industry. As James Anderson from RAND Corporation points out, "The DARPA Challenges solidified partnerships between auto manufacturers and the education sector, and it mobilized a number of endeavors in the automotive sector to advance AVs [autonomous vehicles]."¹⁴⁴

While a fully autonomous vehicle is not yet commercially available, there have been major strides in the decade following the first DARPA challenge. In April 2014, Google's self-driving car surpassed the 700,000-mile mark without a single registered accident.¹⁴⁵ Reports released at the time of the milestone indicated the car could detect and track hundreds of objects simultaneously, including pedestrians and even traffic cones.¹⁴⁶ And while a fully autonomous vehicle may not be readily available to the average customer for some time, many related technologies (such as self-parking, automatic braking, and lane control) have already made it into several high-end models of commercially available automobiles. With the success of the Google car and others like it, the once fantastical idea that autonomous vehicles could safely transport humans from place to place is now considered an understandable possibility.

B. DRIVERS FOR TECHNOLOGICAL MATURATION

The drivers underlying the continued maturation of autonomous vehicles are somewhat unique when compared to other emerging technologies. Because of the cost, complexity, and implications to existing traffic legislation, enhancements to autonomous vehicles are almost entirely driven by the private sector, with support from educational institutions. The U.S. military has also shown some level of interest in these technologies,

¹⁴³ Weber, "Where To?."

¹⁴⁴ Anderson et al., *Autonomous Vehicle Technology*.

¹⁴⁵ Sebastian Anthony, "Google's Self-Driving Car Passes 700,000 Accident-Free Miles," Extreme Tech, April 29, 2014, <http://www.extremetech.com/extreme/181508-googles-self-driving-car-passes-700000-accident-free-miles-can-now-avoid-cyclists-stop-for-trains>.

¹⁴⁶ Ibid.

but has invested comparatively few resources in its continued development.¹⁴⁷ Also somewhat unique for an emerging technology, the primary drivers for technological change are in many cases the same as those that inhibit its proliferation into the market. To achieve a comparative advantage, automakers continually invest in ways to incorporate new technologies, such as auto-park and variable cruise control, into their vehicles, but only insofar as the consumer market will tolerate. Technologies must therefore not only be proven, applicable, and safe, but also relatively inexpensive. Until a technology meets these conditions, those same implementers would be expected to resist its incorporation into existing vehicles standards.¹⁴⁸

On the consumer level, it is currently difficult at best to predict the demand for autonomous vehicles over the next 20 years. Two central reasons for this unpredictability are changing patterns in personal automobile ownership and driving, and public perception of autonomous vehicle technology.

Studies indicate that Americans are driving less and reducing the number of vehicles in their households. After rising almost continually since World War II, the number of drivers in U.S. households has declined nearly 10% since 2004.¹⁴⁹ The average American household now owns fewer than two cars—a level not seen since the early 1990s.¹⁵⁰ This change can be attributed to the fluctuating cost of gasoline and vehicle maintenance, technology that enables telecommuting, and increased public transportation availability.¹⁵¹ Data also suggests these trends will only continue, as younger generations simply have less interest in driving compared to their parents. A study completed in 2013 found that driving by young people decreased 23% from 2001 to 2009.¹⁵² In addition, less than 70% of 19-year-olds in the United States currently have a

¹⁴⁷ Anderson et al., *Autonomous Vehicle Technology*.

¹⁴⁸ Justin Pritchard, “How Google Got States to Legalize Driverless Cars,” Huffington Post, May 30, 2014, http://www.huffingtonpost.com/2014/05/30/google-driverless-cars_n_5416931.html.

¹⁴⁹ Adam Geller, “Americans’ Car Ownership, Driving in Steep Decline,” Huffington Post, May 31, 2014, http://www.huffingtonpost.com/2014/05/31/american-driving-car-decl_n_5424867.html.

¹⁵⁰ Ibid.

¹⁵¹ Elisabeth Rosenthal, “The End of Car Culture,” *New York Times*, June 29, 2013, <http://www.nytimes.com>.

¹⁵² Ibid.

driver's license, down nearly 20% from two decades ago.¹⁵³ This continued decline in automobile demand will have implications to the future of autonomous vehicles.¹⁵⁴ What those implications are remains unclear.

Perhaps more tangible and certainly more immediate than the gradual decline of driving in the United States is the public's opinion of autonomous vehicles. In a market driven by the consumer, polls suggest the public's demand for this technology is lukewarm at best. When asked about their general opinion regarding autonomous and self-driving vehicles, 22% of U.S. respondents had a "very positive" view while roughly 45% had either a neutral or negative view.¹⁵⁵ Interestingly enough, roughly 70% of U.S. respondents believed autonomous vehicles could reduce the overall number of accidents in the United States, but over 60% claimed to be at least "moderately concerned" about driving or riding in one.¹⁵⁶ Furthermore, over 80% of respondents were at least "moderately concerned" with the safety consequences of equipment failure or system failure.¹⁵⁷ The most glaring response to this survey, however, was the amount of extra money respondents were willing to pay to have a completely autonomous vehicle. The median response was zero, while 10% were willing to pay an extra \$5,800.¹⁵⁸ Compared to the roughly \$70,000 in technology it takes to properly operate the Google car, autonomous vehicles have a long way to go to become affordable.¹⁵⁹ The results of this study and others like it indicate that, despite the high-profile Google cars and claims related to overall safety, the public still questions autonomous vehicles' reliability and return on investment.

¹⁵³ Geller, "Americans' Car Ownership."

¹⁵⁴ Alex Davies, "Self-Driving Cars will Make Us Want Fewer Cars," *Wired*, March 9, 2015, <http://www.wired.com/2015/03/the-economic-impact-of-autonomous-vehicles/>.

¹⁵⁵ Brandon Schoettle and Michael Sivak, *A Survey of Public Opinion about Autonomous and Self-Driving Vehicles in the U.S., the U.K., and Australia* (Ann Arbor, MI: University of Michigan Transportation Research Institute, 2014).

¹⁵⁶ *Ibid.*

¹⁵⁷ *Ibid.*

¹⁵⁸ *Ibid.*

¹⁵⁹ Sean V. Casely, Adam S. Jardim, and Alex M. Quartulli, "A Study of Public Acceptance of Autonomous Vehicles," bachelor's thesis, Worcester Polytechnic Institute, 2013.

Contrary to some expert predictions that fully autonomous vehicles will be commonplace in the next 15 years, historical evidence suggests that, even if public demand were high, the deployment cycle for automobile-related technologies is significantly longer.¹⁶⁰ Table 2 highlights the deployment cycle for five separate automobile-related technologies. Interestingly, even with a federal mandate in place and a comparatively simple technology to include in automobile designs, the complete market saturation of air bags took roughly 25 years to achieve.¹⁶¹

¹⁶⁰ Janessa Rivera, “Gartner Says the Self-Driving Vehicle will be the First Pervasive, Personal Robots that most Consumers will Experience in their Lifetime,” Gartner, October 23, 2014, <http://www.gartner.com/newsroom/id/2884317>.

¹⁶¹ Todd Litman, “Autonomous Vehicle Implementation Predictions,” Victoria Transport Policy Institute, February 27, 2015.

Table 2. Vehicle Technology Deployment Summary

Name	Deployment Cycle	Typical Cost Premium	Market Saturation Share
Air Bags	25 years (1973–1998)	< \$500	100% due to mandates
Automatic Transmission	50 years (1940–1990)	\$1500	90% U.S., 50% worldwide
Navigation Systems	30+ years (1985–2015+)	\$500 (rapidly declining)	Uncertain; probably 80%
Optional GPS Services	15 years	\$250 annually	2–5%
Hybrid Vehicles	25 years (1990–2015+)	\$5,000	Uncertain; currently ~4%

After Litman, Todd. “Autonomous Vehicle Implementation Predictions.” Victoria Transport Policy Institute. February 27, 2015. <http://www.vtpi.org/avip.pdf>.

The future of truly autonomous vehicles remains somewhat murky, but this has not stopped many U.S. state governments, and to some degree even the federal government, from taking proactive stances in the development of legislation long before widespread public use. Legislative barriers still exist preventing complete public adoption, but rarely has legislation kept up with the pace of an emerging technology like it has with autonomous vehicles.¹⁶²

C. CURRENT POLICY LANDSCAPE

Industry experts predict that fully autonomous vehicles will not be available for purchase by the general public for another decade, if not longer. Factors—such as the extended lifespan of current vehicles, higher projected purchase prices for autonomous vehicles, and additional operating requirements, like special permits or licenses—suggest that even if autonomous vehicles were publicly available, it would take much longer to realize their widespread adoption.¹⁶³ Despite these predictions, state and federal policymakers have already begun to implement laws and issue guidelines intended to shape the industry’s future. Not all experts agree on the potential implications of the collective body of legislation to date, but with the rate of increase in the capabilities of autonomous vehicles, more legislation is certainly on its way.

In 2012, working directly with a team of representatives from Google, Nevada became the first state in the United States to grant licenses for autonomous vehicles.¹⁶⁴ The Nevada legislation does not grant unrestricted use of autonomous vehicles, but identifies specific conditions under which these cars can be legally operated. Later that same year, Governor Jerry Brown signed a similar bill approving the use of autonomous vehicles in California.¹⁶⁵ While autonomous vehicle legislation at the state level started slowly, it gained momentum over the last four years. The National Conference of State Legislatures notes that 16 states introduced legislation related to autonomous vehicles in

¹⁶² Anderson et al., *Autonomous Vehicle Technology*.

¹⁶³ Litman, “Autonomous Vehicle Implementation Predictions.”

¹⁶⁴ Matt Peckham, “Google’s Driverless Cars Now in Nevada,” *Time*, May 08, 2012, <http://techland.time.com/2012/05/08/googles-driverless-cars-now-officially-licensed-in-nevada/>.

¹⁶⁵ Pritchard, “How Google Got States.”

2015, up from 12 states in 2014, nine states and Washington, DC in 2013, and six states in 2012.¹⁶⁶

Barriers to the development of autonomous vehicle legislation at the state level vary, but common themes can be identified. While few, if any, state vehicle codes expressly prohibit the use of autonomous vehicles, the interpretation of current legislation could complicate the matter. These codes were written with the assumption that a human driver would be operating the vehicle, so legislation is often incompatible with the concept of a driverless vehicle. In one somewhat unique example, the State of New York requires that at least one hand remain on the wheel at all times.¹⁶⁷ Clearly, a revision of current legislation would have to occur for autonomous vehicles to be allowed to operate in a state with such a requirement. Other state codes are more general but require the driver to be attentive and have the capacity to safely operate the vehicle at all times. Research on the varying legal interpretations of these codes is currently underway and nearly everything, even the definition of the term “driver,” is being examined.¹⁶⁸

Beyond conflicts in existing regulation, another potential barrier to the development of state-level policy is resistance from powerful lobbying groups. Because states are developing their own legislation, lobbyist and lawyer attention is focused at the state level. Prior to the signing of the legislation in California in 2012, the Alliance for Automobile Manufacturers pushed to have many of the allowances for autonomous vehicles removed from the final bill. The advocacy group, which includes members from the 12 largest automobile manufacturers, feared automakers would be liable for any failure of Google technology strapped to their cars.¹⁶⁹ Conversely, it was the trial lawyers, a powerful constituency in the state, and interactions with Google representatives that successfully lobbied to keep the automakers liable.¹⁷⁰ Similar to the

¹⁶⁶ “Autonomous Vehicle Legislation,” National Conference of State Legislatures, June 18, 2015, <http://www.ncsl.org/research/transportation/autonomous-vehicles-legislation.aspx>.

¹⁶⁷ Bryant Walker Smith, “Automated Vehicles are Probably Legal in the United States,” *Texas A&M Law Review*, 1 (2014): 411–521.

¹⁶⁸ *Ibid.*

¹⁶⁹ Pritchard, “How Google Got States.”

¹⁷⁰ *Ibid.*

current legislative landscape for UASs, it is this type of environment that, in the absence of an overarching federal policy, produces inconsistent legislation at the state level.

At the federal level, the U.S. Department of Transportation's (USDOT) National Highway Traffic Safety Administration (NHTSA) is responsible for "developing, setting, and enforcing federal motor vehicle safety standards (FMVSSs) and regulations for motor vehicles and motor vehicle equipment."¹⁷¹ In May 2013, NHTSA issued a preliminary policy statement about the use of autonomous vehicles. The 14-page document can be divided into three overarching categories:

- An explanation of the many areas of vehicle innovation and types of automation that offer significant potential for enormous reductions in highway crashes and deaths
- A summary of the research NHTSA has planned or has begun to help ensure that all safety issues related to vehicle automation are explored and addressed
- Recommendations to states that have authorized operation of self-driving vehicles, for test purposes, on how best to ensure safe operation as these new concepts are being tested on highways¹⁷²

Despite acknowledging their role in the development of a national policy for the incorporation of autonomous vehicles onto the Nation's highways, NHTSA's policy document essentially only provides general recommendations for states looking to develop their own autonomous vehicle policies. The NHTSA document does provide a classification system for states to consider when developing their own codes but, once

¹⁷¹ "Preliminary Statement of Policy Concerning Automated Vehicles," National Highway Traffic Safety Administration, May 2013.

¹⁷² "U.S. Department of Transportation Releases Policy on Automated Vehicle Development," National Highway Traffic Safety Administration, May 30, 2013. <http://www.nhtsa.gov/About+NHTSA/Press+Releases/U.S.+Department+of+Transportation+Releases+Policy+on+Automated+Vehicle+Development>.

again, these are merely recommendations that carry no weight of law.¹⁷³ In fact, Motor Authority noted that NHTSA “has considerable concerns regarding state regulation on safety of self-driving vehicles and does not recommend states only permit the use of such vehicles for testing purposes.”¹⁷⁴ Again, because NHTSA has to date issued only recommendations, states can continue to address these issues as they deem appropriate.

In summary, actual laws pertaining to the use of autonomous vehicles are almost non-existent at the federal level. While NHTSA has provided a useful framework for consideration, it has not proposed anything beyond state-level recommendations. More activity has occurred at the state level, but bills are inconsistent from state to state. All bills tend to highlight the importance of autonomous vehicles and the need for additional research, but only a few actually lay the legislative groundwork for vehicle testing.¹⁷⁵ States with more sophisticated legislation, like Nevada, often worked directly with the private sector while developing policies. While overregulation could limit the future potential of this technology, the absence of a coordinated federal policy has created a patchwork of ad hoc state legislation and ensured this pattern is bound to continue.

¹⁷³ Richard Read, “NHTSA Lays Out Groundrules for Autonomous Vehicles,” The Car Connection, June 7, 2013, http://www.thecarconnection.com/news/1084651_nhtsa-lays-out-groundrules-for-autonomous-vehicles; The classification of autonomous vehicles defined by the NHTSA has been widely accepted for use in state-level policy. The four categories are: “**Level 1**—Function-specific Automation: Automation of specific control functions, such as cruise control, lane guidance and automated parallel parking. Drivers are fully engaged and responsible for overall vehicle control (hands on the steering wheel and foot on the pedal at all times). **Level 2**—Combined Function Automation: Automation of multiple and integrated control functions, such as adaptive cruise control with lane centering. Drivers are responsible for monitoring the roadway and are expected to be available for control at all times, but under certain conditions can disengage from vehicle operation (hands off the steering wheel and foot off pedal simultaneously). **Level 3**—Limited Self-Driving Automation: Drivers can cede all safety-critical functions under certain conditions and rely on the vehicle to monitor for changes in those conditions that will require transition back to driver control. Drivers are not expected to constantly monitor the roadway. **Level 4**—Full Self-Driving Automation: Vehicles can perform all driving functions and monitor roadway conditions for an entire trip, and so may operate with occupants who cannot drive and without human occupants.” More detailed information can be found in the Preliminary Statement of Policy Concerning Automated Vehicles, National Highway Traffic Safety Administration, May 2013.

¹⁷⁴ Richard Read, 2013.

¹⁷⁵ Moon K. Moon, Yaniv Heled, Isaac Asher, and Miles Thompson, “Comparative Analysis of Laws on Autonomous Vehicles in the U.S. and Europe,” Paper presented at the AUVSI Unmanned Systems Conference, Orland, FL, May 2014. http://www.auvsishow.org/auvsi2014/Custom/Handout/Speaker8657_Session789_1.pdf

D. SUMMARY

As noted in this chapter, the characteristics of autonomous vehicle technology have kept it relatively confined to a select number of stakeholders. While these stakeholders remain few, namely automobile manufacturers and Google, the implications of the proliferation of this technology could be global. Because of this potential policymakers in the United States have been proactively working to develop policy in conjunction with the private sector (see Table 3). Despite predictions that a fully autonomous vehicle will not be made available to the public before 2020, the policy work being undertaken now will assist in its incorporation onto the nation's public roads.

Table 3. Autonomous Vehicle Policy Summary

Autonomous Vehicle Policy Summary	
<i>Federal</i>	<ul style="list-style-type: none">• <i>May 2013</i>— NHTSA releases its Preliminary Statement of Policy Concerning Automated Vehicles.
<i>State</i>	<ul style="list-style-type: none">• <i>Since 2012</i>, 31 states have considered legislation related to autonomous vehicles• As of 2015, Seven states have enacted autonomous vehicle legislation<ul style="list-style-type: none">○ Legislation varies significantly from state to state○ States with enacted laws often worked very closely with private sector stakeholders
<i>Other</i>	<ul style="list-style-type: none">• No specific guidelines but Google has been consistently working with states on drafting legislation for the testing of autonomous vehicles

V. ADDITIVE MANUFACTURING

To many, the additive manufacturing technology that enabled the sudden proliferation of the personal 3D printer seemed to develop overnight. This, however, is not the case; the origins of modern additive manufacturing processes can be traced back well over 100 years. While a detailed historical account of additive manufacturing's evolution is not central to this paper, a brief overview of the more recent advancements in the industry is critical to understand many of the misconceptions associated with this manufacturing process.

In September, 2009 a group of 65 experts in the field of additive manufacturing met in Washington, DC to develop a historical roadmap for the industry.¹⁷⁶ This roadmap was designed to not only examine the origins of additive manufacturing processes, but to identify critical areas of focus that could advance the associated sciences in the following decade. Much of the information pertaining to the origins of additive manufacturing in this chapter has been gleaned from the final report developed from that meeting. Information on more modern developments of additive manufacturing has been acquired through the annual *Wohlers Report 2014*, a recognized industry expert.

Processes that formed the underlying principles of modern additive manufacturing can be traced back to topographical maps and photo-sculptures in the late 1800s.¹⁷⁷ Early pioneers in these fields consistently looked for ways around the limitations of the typical subtractive methods, the then-standard manufacturing processes of the day, and began to find them in comparatively crude and labor-intensive forms of current additive manufacturing techniques.¹⁷⁸ Advancements in the field of photography enabled limited refinement to previously crude methods, but true progress within the industry did not occur until the second half of the 20th century.¹⁷⁹ The concept of additive manufacturing

¹⁷⁶ David L. Bourell, "A Brief History of Additive Manufacturing and the 2009 Roadmap for Additive Manufacturing: Looking Back and Looking Ahead," US-Turkey Workshop on Rapid Technologies, September 24, 2009, 1.

¹⁷⁷ Ibid

¹⁷⁸ Ibid.

¹⁷⁹ Ibid.

as a true industrial process began to gain momentum in the 1970s as improvements in laser technology made it possible to apply and, more importantly, control enough heat to melt a myriad of substances that could then be bonded layer by layer.¹⁸⁰ Despite the developments in laser technology, none of these early techniques produced a working machine capable of replicating the process for industrial or personal use.

Experts commonly attribute the origin of modern 3D printing to Charles Hull. In 1986, Hull was issued the first patent for stereolithography—an additive manufacturing method that is addressed later in this paper.¹⁸¹ Hull had been working on a design for a machine to successfully employ stereolithography in the manufacturing process since 1983, and after years of testing sold the first commercial system in 1988.¹⁸² As Hull perfected his method, several other technologies and processes began to emerge, all of which would eventually have their own impact on the industry.¹⁸³ While these processes differed significantly from Hull's, they all contained similar, almost entirely industrial, applications—more specifically, industrial prototyping.¹⁸⁴

It was not until the late 1990s that the industry began to visibly expand in a number of different directions, ushering in a new era of 3D printing. According to 3D Printing Industry,

During the mid-nineties, the sector started to show signs of distinct diversification with two specific areas of emphasis that are much more clearly defined today. First, there was the high end of 3D printing, still very expensive systems, which were geared towards part production for high value, highly engineered, complex parts. At the other end of the spectrum, some of the 3D printing system manufacturers were developing and advancing 'concept modelers' as they were called at the time. Specifically, these were 3D printers that kept the focus on improving concept development and functional prototyping, that were being

¹⁸⁰ Ibid., 8.

¹⁸¹ "History of 3D Printing: The Free Beginners Guide," 3D Printing Industry, accessed May 13, 2015. <http://3dprintingindustry.com/3d-printing-basics-free-beginners-guide/history/>.

¹⁸² Terry Wohlers and Tim Gomet, "History of Additive Manufacturing," in *Wohlers Annual Report 2014* (Fort Collins, CO: Wohlers), 1.

¹⁸³ Matthew Ponsford and Nick Glass, "The Night I Invented 3D Printing," CNN, February 14, 2014, <http://www.cnn.com/2014/02/13/tech/innovation/the-night-i-invented-3d-printing-chuck-hall/>.

¹⁸⁴ "History of 3D Printing: The Free Beginners Guide," 3D Printing Industry.

developed specifically as office- and user-friendly, cost-effective systems; the prelude to today's desktop machines. However, these systems were all still very much for industrial applications.¹⁸⁵

The separation between high- and low-end machines in the late 1990s was critical to the current additive manufacturing landscape. The research into the development and output of high-end additive manufacturing machines continued along a relatively constant and predictable trajectory. The mere cost of these high-end machines (more than \$500,000) made them inaccessible to the average consumer, limiting exposure and investments to large companies or governments—a pattern that still exists today.¹⁸⁶ While significant advancements have been made in the more sophisticated sector of additive manufacturing, the path to achieve those innovations has been much different than that of the low-end sector.

Advancements in technologies required for the low-end additive manufacturing machines led to surprising industry changes. After nearly two decades of a strict industrial focus, the personal 3D printing “revolution” started in 2005 with an open-source project dubbed RepRap.¹⁸⁷ The idea behind the RepRap concept was to create a machine that could essentially produce its own parts. More importantly, the open-source concept meant that many of the ideas, designs, information, and technologies associated with this machine ended up in the hands of a much wider audience.¹⁸⁸ Tinkerers, inventors, and those simply interested in the concept of 3D printing could study, experiment, tweak and begin to design their own machines at a very low cost. As a result, the first commercially available 3D printer based on the RepRap concept was offered for sale in January 2009.¹⁸⁹

¹⁸⁵ Ibid.

¹⁸⁶ “Guide to Professional 3D Printers,” Sculpteo, July 22, 2014, <http://www.sculpteo.com/blog/2014/07/22/list-of-professional-3d-printers/>.

¹⁸⁷ Dale Dougherty, “A Brief History of Personal 3D Printing,” in *Make: Ultimate Guide to 3D Printing 2014*, Mark Frauenfelder (ed.) (Sebastopol, CA: Maker Media, 2013).

¹⁸⁸ Ibid

¹⁸⁹ 3D Printing Industry: History.

While the RepRap project's original intent was to promote opportunities for free design and foster innovation in a less commercialized environment, the concept produced the exact opposite effect.¹⁹⁰ As the editors for 3D Printing Industry note, "Since 2009, a host of similar deposition printers have emerged with marginal unique selling points (USPs) and they continue to do so. The interesting dichotomy here is that, while the RepRap phenomenon has given rise to a whole new sector of commercial, entry-level 3D printers, the ethos of the RepRap community is all about Open Source developments for 3D printing and keeping commercialization at bay."¹⁹¹ By freely handing over the designs for this technology to anyone interested, the minds behind the RepRap project sent the development of the personal 3D printer on a totally unanticipated trajectory. Openly sharing ideas to collectively improve a specific process did little more than lay the groundwork for a slate of new patents in personal 3D printing—patents that are, in many cases, minor tweaks to existing technologies.¹⁹²

Understanding these events' implications helps inform the current landscape of additive manufacturing. On the high-end side, companies continue to invest in pushing the boundaries of the most sophisticated additive manufacturing technologies. Specific examples of these advancements include innovations in the biomedical arena, national security sector, and aerospace sector. Recognizing the market's potential growth, traditional manufacturers of industrial 3D printers are also developing and producing their own low-end personal printers. Meanwhile, smaller companies and even individuals continue to develop unique, low-end 3D printers claiming similar capability and functionality to their superior relatives but with significantly lower starting costs. This is only possible due to the varying methods of 3D printing, which are covered in the next section of this chapter. While this has had a positive impact on innovation and development for the additive manufacturing process, the concept of international standardization employed by many traditional sectors remains elusive.¹⁹³

¹⁹⁰ *Idid.*

¹⁹¹ *Ibid.*

¹⁹² *Ibid.*

¹⁹³ "The History of Additive Layer Manufacturing" University of Exeter Centre for Additive Layer Manufacturing, accessed April 2014, <http://emps.exeter.ac.uk/engineering/research/calm/whatis/history/>.

A. METHODS

This section introduces several popular forms of current additive manufacturing processes. It is important to understand there are many different manufacturing processes that fall under the umbrella term of additive manufacturing, and while these processes are vastly different in complexity, technologies employed, and materials used, the common factor is the manner in which production is carried out. Each of the following examples involves a device that builds a product from nothing by fusing one layer on top of another. This is the key difference between additive manufacturing and traditional subtractive manufacturing methods, which begin with a block of material and cut away excess material until the desired product is formed.¹⁹⁴

Stereolithography is often described as one of the earliest forms of modern additive manufacturing.¹⁹⁵ During the 1992 Solid Freeform Fabrication Symposium in Austin, Texas, Dr. Paul F. Jacobs, then-director of research and design at 3D Systems in Valencia, California, described stereolithography in specific scientific detail.¹⁹⁶ For the purposes of this paper, a simplified version of the process suffices. First, a 3D rendering of the object to be created is sliced into very thin layers using some type of computer-aided design (CAD) software. That information is then passed to the device that projects an intense beam of ultraviolet light into a vat of liquid photopolymer, a substance that undergoes a physical or chemical change when exposed to light.¹⁹⁷ The beam of ultraviolet traces a pattern in the vat of liquid according to each layer being transmitted via the CAD software, solidifying the liquid photopolymer as it makes each pass. Each cross section that has hardened is then lowered into the remaining liquid photopolymer

¹⁹⁴ “Additive vs. Subtractive Manufacturing,” *Efficient Manufacturing*, January 2013: 50–54. <http://www.efficientmanufacturing.in/pi-india/index.php?StoryID=443&articleID=129947>.

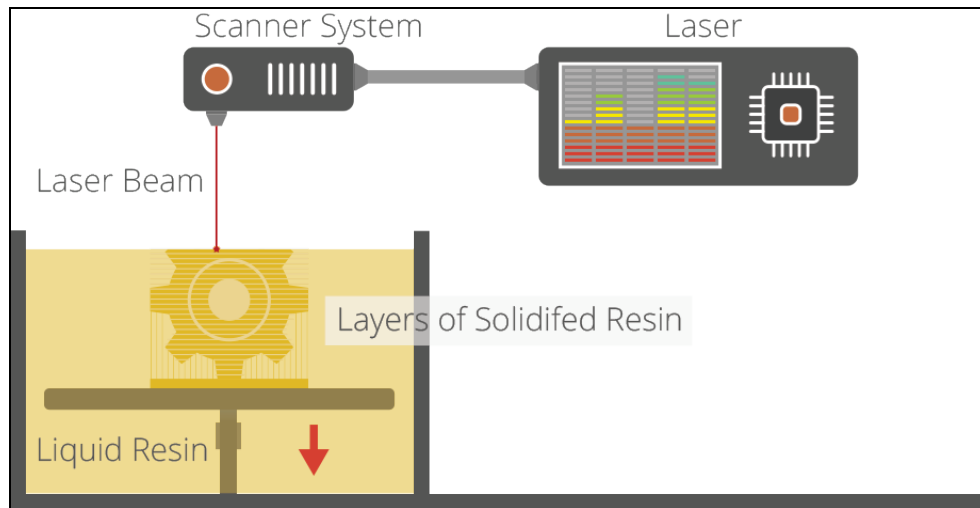
¹⁹⁵ Paul F. Jacobs, *Rapid Prototyping & Manufacturing: Fundamentals of Stereolithography*. (Dearborn, MI: Society of Manufacturing Engineers, 1992), 1.

¹⁹⁶ Paul F. Jacobs, “Fundamentals of Stereolithography,” in *Solid Freeform Fabrication Symposium Report* (September 1992): 196–211.

¹⁹⁷ “Photopolymer,” Dictionary.com, accessed May 13, 2015, <http://dictionary.reference.com/browse/photopolymer>

and the process continues, layer by layer, until the product is complete.¹⁹⁸ The diagram in Figure 4 visualizes this process.

Figure 4. Process of Stereolithography



From 3D Printing Industry. "3D Printing Processes: The Free Beginners Guide." Accessed May 13, 2015. <http://3dprintingindustry.com/3d-printing-basics-free-beginners-guide/processes/>.

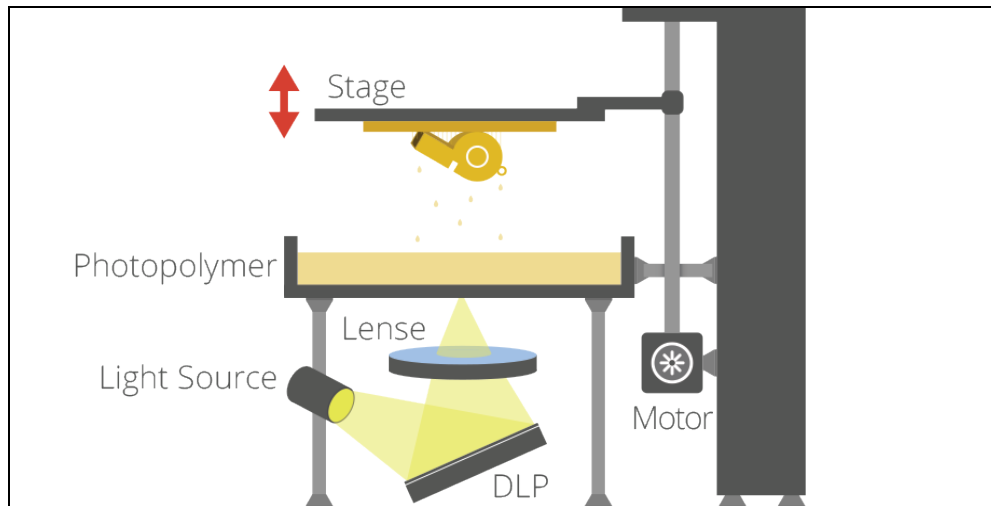
Similar to stereolithography, digital light processing (DLP), uses a light source to create layers within a vat of photopolymers (see Figure 5). The significant difference between the two methods is the source of light. While stereolithography uses an ultraviolet light to trace a pattern in a vat of liquid photopolymers, digital light processing uses a more conventional light source, such as an arc lamp.¹⁹⁹ The light source is reflected off a series of mirrors and into a lens that causes patterns to cure in the source material. Objects are then either lowered into or raised out of the vat of photopolymers to make room for the next layer. While very similar to stereolithography, digital light processing usually has faster build times, as this technique can create an entire layer in one singular digital image versus the tracing of a focused beam of ultraviolet light as

¹⁹⁸ Jacobs, "Fundamentals of Stereolithography."

¹⁹⁹ Ibid.

described for stereolithography.²⁰⁰ In addition, since both techniques use similar materials, the inherent strengths and weaknesses of each process are the same.²⁰¹

Figure 5. Process of Digital Light Processing



From 3D Printing Industry. "3D Printing Processes: The Free Beginners Guide." Accessed May 13, 2015. <http://3dprintingindustry.com/3d-printing-basics-free-beginners-guide/processes/>.

Selective laser sintering, however, is a completely different method of additive manufacturing. Unlike stereolithography or digital light processing, selective laser sintering does not use a liquid photopolymer, but instead uses a bed of powdered polymer as its building material. A high-powered laser interacts with the surface of the powdered material and either sinters (the heat applied is below the particles' boiling point) or melts (the heat applied is above the particles' boiling point) the particles together into a solid layer.²⁰² As each layer is fused, the powder bed is dropped incrementally to create room for the next layer. As this occurs, a roller within the device levels the surface of the remaining powder bed to prepare for the next layer.²⁰³ See Figure 6 for the visualized process. Selective laser sintering gives the user many more options for building materials

²⁰⁰ "3D Printers and 3D Printing: Technologies, Processes, and Techniques," Sculpteo.

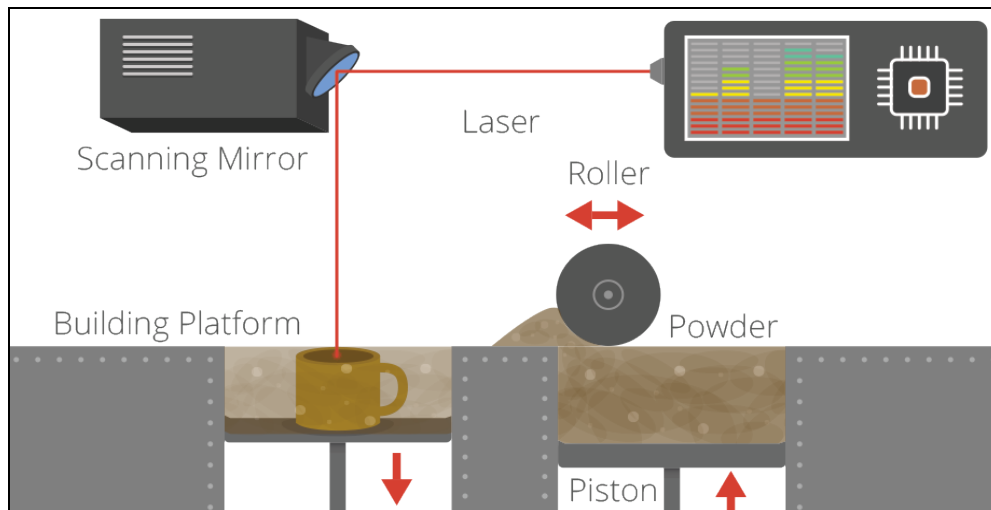
²⁰¹ Ibid.

²⁰² Elizabeth Palermo, "What Is Selective Laser Sintering?," LiveScience, August 13, 2013, <http://www.livescience.com/38862-selective-laser-sintering.html>.

²⁰³ "3D Printing Processes," 3D Printing Industry.

than stereolithography or digital light processing. This process has been used to successfully created objects using plastics, glass, metal, and even ceramics.²⁰⁴

Figure 6. Process of Selective Laser Sintering



From 3D Printing Industry. "3D Printing Processes: The Free Beginners Guide." Accessed May 13, 2015. <http://3dprintingindustry.com/3d-printing-basics-free-beginners-guide/processes/>.

Fused deposition modeling is the most affordable 3D printing process and, as such, it is also the most common additive manufacturing process.²⁰⁵ This method is also one of the simplest, involving a relatively limited number of parts. The process involves begins as two separate materials are fed into a heated extrusion head.²⁰⁶ The primary material is the plastic filament used to create the final product and the secondary material is required to support the model as it is being created. As the materials enter the heated extrusion head, they become pliable. They are then deposited layer by layer in ribbons roughly the size of a human hair.²⁰⁷ Once the object has been completed, the support materials are simply separated from the object and disposed of, leaving only the

²⁰⁴ Palermo, "What Is Selective Laser Sintering?,"

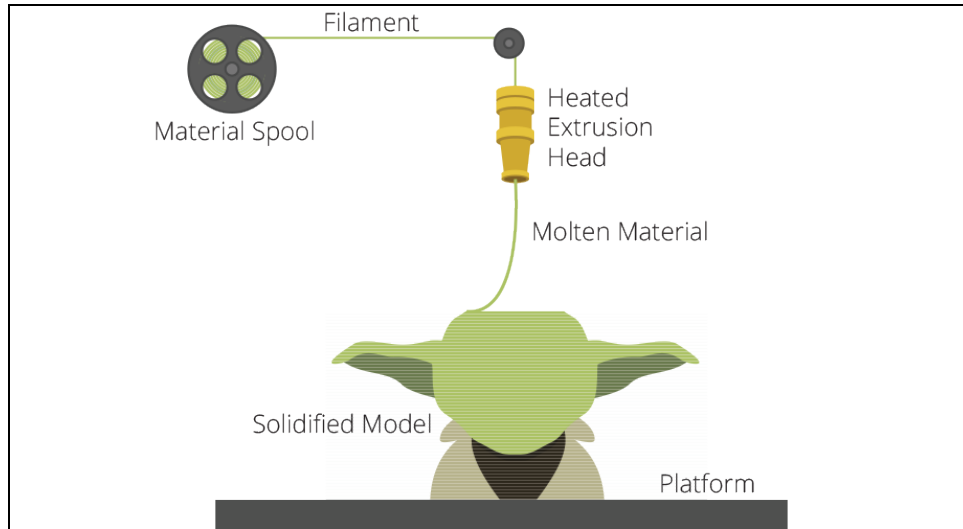
²⁰⁵ "3D Printers and 3D Printing: Technologies, Processes, and Techniques," Sculpteo, accessed, April 12, 2015, <http://www.sculpteo.com/en/3d-printing-technologies/#dlp>.

²⁰⁶ "3D Printing Processes." 3D Printing Industry.

²⁰⁷ Joe Hiemenz, *3D Printing with FDM* (Eden Prairie, MN: Stratsys, 2014).

completed project. While simple in comparison to others, this method of additive manufacturing often requires much longer build times. Given the limited nature of materials available for this process, the types of objects it can create is also limited.

Figure 7. Process of Fused Deposition Modeling



From 3D Printing Industry. “3D Printing Processes: The Free Beginners Guide.” Accessed May 13, 2015. <http://3dprintingindustry.com/3d-printing-basics-free-beginners-guide/processes/>.

These methods are only four of many in the additive manufacturing industry. Internet sites such as Sculpteo and 3D Printing Industry list more than twice as many. With so many existing methods, advances in the myriad of technologies they use could change the entire landscape of the industry. For example, as noted previously, fused deposition modeling is currently the most popular form of 3D printing due to its ease of use and lower costs, but it also has the most limited outputs. This also means that most individuals with 3D printers are somewhat limited in what they can create. Imagine if someone were able to develop an extrusion head that could heat and accurately deposit metals, glass, or other materials using the same basic design as the current low-cost printers. Suddenly, more consumers could have access to devices with much different capabilities. There are already several hobbyists working on creating very powerful 3D

printers in their private garages.²⁰⁸ Any one of these attempts could not only revolutionize the industry, but also force those outside of the industry to consider a new, widespread device's implications.

B. DRIVERS

Similar to the drivers identified in the ongoing enhancement of UAS technology, certain groups' activities and interests will drive maturation in low-end additive manufacturing products, while others will force the high-end, more sophisticated technologies to evolve. Improvements to the high-end systems will continue to be driven by stakeholders who can afford to invest in these already expensive systems. With a myriad of potential uses, the U.S. military continues to invest significant resources in the future application of additive manufacturing processes.²⁰⁹ Using proven additive manufacturing techniques, military scientists are already designing and constructing items for personnel use, such as parts for protective masks, medical prosthetics, and custom holders for bomb-detecting equipment.²¹⁰ 3D printers have also been deployed to the field in Afghanistan to help troops produce small parts on demand. The ultimate goal of many of these scientists, however, is not simply to master current additive manufacturing processes, but to create new processes that continue to push the limits of the technology. As Jaret Riddick, leader of the Army Research Laboratory's Structural integrity and Durability Team, notes, "The desire here is to take this very new sort of technique, additive manufacturing or 3-D printing, that's normally been used for prototyping, and use it to actually manufacture functioning parts. There's a lot that needs to be understood at the very fundamental level to be able to make that leap."²¹¹ The U.S.

²⁰⁸ Signe Brewster, "Why You Won't See a Laser Sintering 3D Printer on Your Desk Anytime Soon," GIGAOM, April 25, 2014, <https://gigaom.com/2014/04/25/why-you-wont-see-a-laser-sintering-3d-printer-on-your-desk-anytime-soon/>.

²⁰⁹ Valerie Insinna, "Military Scientists Developing New 3-D Printing Applications," National Defense, June 2014, <http://www.nationaldefensemagazine.org/archive/2014/June/Pages/MilitaryScientistsDevelopingNew3-DPrintingApplications.aspx>.

²¹⁰ Ibid.

²¹¹ Ibid.

military—hoping to one day be able to print food, skin, and even warheads—will continue to push advances in additive manufacturing processes.²¹²

Unlike the other identified drivers, the medical sector is in a somewhat unique position: it is already capitalizing on enhancements to both high-end and low-end additive manufacturing technologies and, as such, continues to invest resources in both. On the more sophisticated side of the scale, medical researchers are pushing current technology to create models of internal human vascular networks, and to make safer and cheaper pharmaceuticals.²¹³ Innovation on this front is occurring so rapidly that tasks once thought impossible now seem almost commonplace. Just a few years ago, using additive manufacturing technologies to help bones heal properly was considered revolutionary. Today, a similar story would not make most medical blogs. In just one month of reports on 3D Printing.com's medical archive blog, there are examples of researchers using 3D printing technology to create human cartilage implants, develop scaffolds to potentially cure Type-1 diabetes, and even create the world's first 3D printed beating artificial heart cells.²¹⁴ But not all innovation has to be so complex. Researchers and physicians are also using less capable machines to provide medical aid such as custom splits and prosthetics.²¹⁵ However, with goals to eventually print fully functional human organs, the medical industry will play a significant role in driving additive manufacturing innovation.²¹⁶

Finally, similar to the identified drivers of UAS technological innovation, tinkerers will also play a role in future additive manufacturing enhancements. More so

²¹² Andrew Ward, "U.S. Military Poised to Capitalize on 3-D Printing," *Daily Finance*, January 21, 2015, <http://www.dailyfinance.com/2015/01/21/military-testing-3d-printing/>.

²¹³ Jerome Groopman, "Print Thyself," *New Yorker*, November 24, 2014, <http://www.newyorker.com/magazine/2014/11/24/print-thyself>.

²¹⁴ Lav Radis, "Fast Bioprinting of Human Cartilage Implants," 3D Printing.com, March 25, 2015, <http://3dprinting.com/news/fast-bioprinting-of-human-cartilage-implants/>; Joseph Young, "Researchers Develop 3D Printed Scaffolds to Cure Type-1 Diabetes," 3D Printing.com, May 30, 2015, <http://3dprinting.com/medical/researchers-develop-3d-printed-scaffolds-to-cure-type-1-diabetes/>; Joseph Young, "The World's First 3D Printed Beating Artificial Heart Cells," 3D Printing.com, April 18, 2015, <http://3dprinting.com/medical/the-worlds-first-3d-printed-beating-artificial-heart-cells/>.

²¹⁵ Sonya Collins, "Will 3-D Printing Revolutionize Medicine?," *WebMD*, accessed June 1, 2015, <http://www.webmd.com/news/breaking-news/20140723/3d-printing>.

²¹⁶ Groopman, "Print Thyself."

than the previous technologies addressed in this paper, private individuals have openly embraced this role in non-traditional ways. Mark Hatch, the chief executive officer (CEO) of TechShop, a membership-based, do-it-yourself, open-access, fabrication workspace claims that the United States is just beginning to enter into what has been dubbed the Maker Movement.²¹⁷ As the name indicates, this movement is focused on tinkerers' desire to create physical objects and, according to Hatch, several factors make the present better than any time in history for this movement to occur: "Cheap, powerful, and easy-to-use tools play an important role. Easier access to knowledge, capital, and markets also help push the revolution."²¹⁸ A key element of this revolution is a "makerspace," a physical location with a myriad of tools appropriate for simply building things. Of the list of necessary tools for a successful makerspace, Hatch identifies 3D printers, scanners, and related software.²¹⁹ While individuals use the additive manufacturing technology to build other objects, they are also becoming familiar enough with the technology itself to develop their own enhancements. The Maker Movement is but one way, albeit a significant one, that private individuals will continue to drive innovation in additive manufacturing from the bottom up.

C. PUBLIC POLICY

During his 2013 State of the Union Address, President Obama stated, "Last year, we created our first manufacturing innovation institute in Youngstown, Ohio. A once-shuttered warehouse is now a state-of-the art lab where new workers are mastering the 3D printing that has the potential to revolutionize the way we make almost everything. There's no reason this can't happen in other towns."²²⁰

When the President of the United States of America made it a point to mention an emerging technology in the State of the Union Address, one might have assumed actions

²¹⁷ Mark Hatch, *The Maker Manifesto* (New York: McGraw Hill, 2014), 3.

²¹⁸ *Ibid.*, 5.

²¹⁹ *Ibid.*, 24.

²²⁰ President Barack Obama, "2013 State of the Union Address," White House Office of the Press Secretary, February 2013, <https://www.whitehouse.gov/the-press-office/2013/02/12/remarks-president-state-union-address>.

to determine the potential public policy implications of said technology were well underway. In the case of additive manufacturing, this was far from the case. Contrary to the ease at which President Obama stated this technology could spread to “other towns,” the one element that could certainly inhibit the further proliferation of an emerging technology is its mismanagement in public policy.

The reference to 3D printing in Obama’s 2013 speech was a bit of a misstatement. His comment was intended to highlight the potential benefits advancements in the field of additive manufacturing could bring to the manufacturing sector in the United States, which has struggled to compete globally over the past several decades.²²¹ Since different methods of additive manufacturing have been employed to some degree in the U.S. manufacturing sector since the 1970s, there have been limited considerations to the impact these technologies could have on public policy, and vice versa.²²² The President was not referencing the sudden and drastic increase in the use of personal 3D printers within the last five years—often a point of confusion due to the inconsistencies in sector-specific nomenclature previously discussed in this paper. Academic research on the role of public policy and regulation as it pertains to these latest trends in personal 3D printing has been somewhat scarce and seemingly reactionary, focused on addressing the most immediate issues raised by a technology that is changing faster than legislators’ pens. The majority of current public policy discourse can be placed into one of four overarching categories: copyright and intellectual property rights, economic implications, individual liability concerns, and gun control. Two of these topics have at least managed to initiate some level of national level dialogue: copyright considerations and gun control.

3D printing’s impact on copyright and intellectual property rights is currently receiving significant attention via corporate sponsored research and academia. This is of little surprise, as traditional views on issues pertaining to copyrights, patents, industrial

²²¹ Justin Pierce and Peter K. Scott, *The Surprisingly Swift Decline of U.S. Manufacturing Employment* (NBER Working Paper No. 18655) (Washington, DC: National Bureau of Economics, 2012).

²²² Bourell, “A Brief History of Additive Manufacturing.”

designs, and trademarks are at risk of being upended by 3D printing technologies.²²³ Designs that were once tightly controlled by the private sector are now at risk of being easily, and relatively cheaply, reproduced by the consumer. Products that cost companies millions in research and design, marketing, and delivery can now be replicated for very little once in the hands of the general population. Makerbot, a company that sells 3D printers, provides a current example of what the future might hold. Markerbot also runs Thingiverse—a website on which individuals share their designs for 3D printers.²²⁴ While the company touts the site as a way to promote open sharing of 3D designs amongst hobbyists, many of the items on the site are actually protected by copyright.²²⁵ Current 3D printing technology has already enabled those with modest 3D printers to replicate, reproduce, and share the designs for copyrighted material, and this trend will only continue as the related technologies enable increased sophistication.

To further complicate these issues, while copyright and intellectual property right legislation is relatively sophisticated in the United States, laws often do not transcend national boundaries. Due to issues of national sovereignty, differing political systems, and cultural traditions, there has never been a universal international copyright law:²²⁶ “The Berne Convention and the Trade-Related Aspects of Intellectual Property Rights (TRIP) Agreement attempt to harmonize copyright laws around the world, but these multilateral conventions have yet to create a uniform intellectual property regime under which all member countries have identical copyright laws.”²²⁷ The complications brought to the debate by the mere global characteristics of the Internet suggests no universal agreement will be made on these issues in the near future.

²²³ Nathan Schissel, “3D Printing and Implications on Intellectual Property Rights,” Technology Law Advisor, November 10, 2014, <http://technologylawadvisor.com/3d-printing-and-implications-on-intellectual-property-rights/>.

²²⁴ Steve Henn, “As 3-D Printing Becomes More Accessible, Copyright Questions Arise,” NPR, February 19, 2013, <http://www.npr.org/sections/alltechconsidered/2013/02/19/171912826/as-3-d-printing-become-more-accessible-copyright-questions-arise>.

²²⁵ Ibid.

²²⁶ Peter K. Yu, “Conflict of Laws Issues in International Copyright Cases,” GigaLaw. April 2001. <http://www.peteryu.com/gigalaw0401.pdf>.

²²⁷ Ibid.

While some predict that, if not appropriately addressed via legislation, copyright infringement could have devastating effects on the future of many private sector companies within the United States, others have offered a different perspective. Michael Weinberg, a lawyer for an open-Internet advocacy group, argues it is the private sector that needs to adapt. Weinberg states, “The technology is coming whether we like it or not. And so as a CEO of one of these companies, you can spend a lot of time and money trying to sue it out of existence—and sue the genie back into the bottle—or you can spend that same time and money and apply it toward finding a way to use the technology to your advantage.”²²⁸ Individual lawsuits notwithstanding, the private sector will need support from well-informed policymakers as the implications of these changes have a direct impact on the U.S. economy as well.

Of the categories highlighted in this section, the role of 3D printing in gun control has been the most prominent in popular press. The U.S. gun control debate is both popular and divisive, so it comes as no surprise the popular media would focus on this particular aspect of modern 3D printing.²²⁹ In 2012, following some of the worst gun-related violence in U.S. history, Defense Distributed gained national notoriety for developing an untraceable AR15 receiver that could be created entirely on a 3D printer.²³⁰ In direct defiance to several state laws banning high-capacity magazines in assault rifles, Defense Distributed placed these designs on the Internet to be freely downloaded.²³¹

While Defense Distributed pushed the legal envelope with their untraceable AR15 receivers and high capacity magazines, it was Cody Wilson’s *Liberator*, a plastic gun that can be produced entirely in a 3D printer, that finally forced the federal government to

²²⁸ Henn, “As 3-D Printing Becomes More Accessible.”

²²⁹ Lisa Miller, “Divisiveness is the Only Constant in the U.S. Gun-Control Debate,” *New York Magazine*, January 9, 2015, <http://nymag.com/daily/intelligencer/2015/01/america-is-still-divided-about-gun-control.html>.

²³⁰ “National Tracing Center,” Bureau of Alcohol, Tobacco, Firearms, and Explosives.

²³¹ “Cody Wilson: Troll, Genius, Patriot, Provocateur, Anarchist, Attention Whore, Gun Nut or Second Amendment Champion?” *Arkansas Times*, January 09, 2014, <http://www.arktimes.com/arkansas/cody-wilson-troll-genius-patriot-provocateur-anarchist-attention-whore-gun-nut-or-second-amendment-champion/Content?oid=3173005&showFullText=true>.

take notice. In April 2013, reacting to Wilson and Defense Distributed, Senator Steve Israel introduced a bill that sought to overhaul the Undetectable Firearms Act (UFA) of 1988 to include specific provisions targeting 3D printed weapons.²³² Israel noted, “When I started talking about the issue of completely plastic firearms, I was told the idea of a plastic gun is science fiction. That science fiction is now a dangerous reality.”²³³ Even with a Republican co-sponsoring the bill, strong opposition from the National Rifle Association (NRA) and lukewarm support from gun control advocates essentially killed Israel’s proposals.²³⁴ The UFA of 1988 was renewed for another decade but no additional considerations for the implications of 3D printed guns were made. Sadly, many believe it will take more than Israel’s efforts for legislators to finally address the issues. As Israel suggested, “A single, real-world incident involving those potentially deadly weapons would bring them back into the spotlight.”²³⁵

D. SUMMARY

As this chapter has highlighted, comparatively little has been done via policy to address the known issues pertaining to additive manufacturing (see Table 4). Despite concerns surrounding the development of illicit weaponry and known copyright issues, additive manufacturing policy has gained little traction at the national level. Similar to the unexpected proliferation of UASs, the use of additive manufacturing technology; namely the personal 3D printer, has drastically increased over the last five years. With this trend only expected to continue, policymakers need to address these known issues while also collaborating with appropriate stakeholders to identify unknown issues.

²³² Mead, “Congress’s Plastic Gun Ban.”

²³³ Andy Greenberg, “Bill to Ban Undetectable Printed Guns is Coming Back,” *Wired*, April 6, 2015, <http://www.wired.com/2015/04/bill-ban-undetectable-3-d-printed-guns-coming-back/>.

²³⁴ *Ibid.*

²³⁵ *Ibid.*

Table 4. Additive Manufacturing Policy Summary

Additive Manufacturing Policy Summary	
<i>Federal</i>	<ul style="list-style-type: none"> • <i>December 2013</i> – Congress extends the Undetectable Firearms Act without a provision referencing 3D printed weapons
<i>State</i>	N/A
<i>Other</i>	<ul style="list-style-type: none"> • The private sector and academia continue to review current copyright and intellectual property right legislation to identify foreseeable gaps with the widespread adoption of advancing additive manufacturing technology

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VI. FINDINGS, RECOMMENDATIONS, AND CONCLUSIONS

The comparative study of unmanned aerial systems (UAS), autonomous vehicles, and additive manufacturing offers interesting insight into the processes behind and the development—or lack thereof—of informed public policy. Evidence suggests factors that typically aid in this public policy development, such as direct government involvement in the creation and evolution of a given technology, did not have the anticipated effects. In fact, the evidence suggests the characteristics of the technology itself have more to do with whether or not legislators are prepared for its emergence.

A. FINDINGS

Based on the examples covered in this paper, the following characteristics can be found in an emerging technology more likely to surprise policymakers: the technology evolves quickly; it has a low price point for entry; and the impacted stakeholders cross industries or sectors.

(1) Technology Evolves Quickly

UAS—While modern UASs have been used by the military since before the Vietnam War, the rapid advancements in technology since their adoption by the private sector have been incredible. Cameras have become smaller, lighter, and yet more capable than ever. Batteries have also become smaller and more powerful, enabling longer flight times for devices. More advanced GPS and computer technology also give the private sector and private citizens access to technology that was once reserved for sophisticated military operations.

Autonomous Vehicles—Inventors, automobile companies, and academia have been working to develop and improve the autonomous vehicle since the 1930s. With the focus changing from the vehicle to the road, and then back to the vehicle again, this technology's evolution has been relatively slow. Although advancements in the past decade have provided for more rapid advancements, it will still be at least a decade before the technology can be introduced to the public at large.

Additive Manufacturing—Much like UASs, modern additive manufacturing practices go back decades, but the explosion of low-end 3D printing technologies in the past decade caught many by surprise. Both high-end 3D systems and low-end 3D printers are increasing in their capabilities and sophistication quite rapidly, especially in the field of medicine and biotech.

(2) Technology Has a Low Price Point for Entry

UAS—For the private sector and the individual, the price point for entry into this market continues to decline while the devices' capabilities increase. Cameras, GPS, and batteries are more capable than ever but are also less expensive. A decent UAS for private use is now a fraction of the cost of previous versions and can be purchased from many different vendors.

Autonomous Vehicle—The price for the technology necessary to build an autonomous vehicle is still incredibly complicated and expensive. The myriad of sensors necessary to operate the autonomous vehicles is estimated between \$75,000-\$100,000.²³⁶ This means further technological advancement will primarily originate with private sector companies or the government.

Additive Manufacturing—As more individuals obtain the technology and more refinements are made, there are continually more options for the low-end 3D printers. At the same time, established companies producing high-end 3D systems have also begun developing their low-end counterparts, increasing competition and continuing to drive down costs.

(3) Technology Stakeholders Cross Industries or Sectors

UAS—Because of the wide range of potential uses for the technology, the development of informed policy for incorporating UASs into the national airspace requires input from a myriad of stakeholders including the FAA, DOJ, DHS, state representatives, the law enforcement community, the private sector, and private citizens.

²³⁶ Ashley Hasley III, "Driverless Cars: 15 Things you need to Know," Washington Post, August 25, 2014, http://www.washingtonpost.com/local/trafficandcommuting/driverless-cars-15-things-you-need-to-know/2014/08/25/786c6fbc-d79b-11e3-95d3-3bcd77cd4e11_story.html.

Each of these groups presents a separate set of challenges that must be considered when addressing the ways in which this technology will be implemented domestically.

Autonomous Vehicle—The policy implications for the incorporation of autonomous vehicles onto public roads directly impacts NHTSA, individual state representatives, and the few private sector companies with vested interests in this technology’s future. Relatively speaking, the group required for coordinating solid policy measures is small when compared to other emerging technologies.

Additive Manufacturing—There are many industries heavily invested in this technology at present, and to the number will only increase as additive manufacturing becomes more sophisticated. As this paper illustrates, there are clear implications to our legal system regarding copyright issues, the medical sector, homeland security, national security, law enforcement community, and the private sector, to include the private citizen.

B. FINDINGS SUMMARY

Despite indications that its public availability is still at least a decade away, the findings of this research suggest that public policy regulating autonomous vehicles to U.S. public roads is more mature than that of UASs or additive manufacturing. The most significant indicator for this conclusion is the legislative posture of policymakers when addressing issues raised by these emerging technologies. In the case of UASs, for example, state-level legislative bodies are primarily reactive, focused on passing policy to curtail a specific issue or activity after it occurs. In the case of additive manufacturing, what little legislation has been proposed has also focused on eliminating an activity’s product after the activity has occurred, such as 3D printed guns or issues with copyright violations. The environment in which policies are being created for autonomous vehicles is much different. While NHTSA, the lead federal agency for this effort, has not released official legislation, it has developed a series of recommendations for states looking to draft their own technology-related policies. This suggests that while NHTSA is already considering the implications this technology could have in the future, it has been careful to not overreact with unnecessary regulation of its own. As noted, a slowly evolving

technology, a high price point for entry, and a somewhat limited stakeholder group are all factors that enable policymakers to address concerns raised by autonomous vehicles in a much more concerted effort than those forced to address UASs or additive manufacturing.

It is also important to note that, of all the elements introduced in this paper, the one that separates the development of public policy for autonomous vehicles from the others is the level of government engagement with private sector stakeholders and academia. From the DARPA-sponsored challenge races, which linked U.S. military sponsors with academics, to Google representatives' direct involvement in Nevada legislation, the private sector has worked much closer with policymakers on issues related to autonomous vehicles than either UAS or additive manufacturing to date. In fact, this author was unable to locate significant data on any public-private partnerships focused on either UASs or additive manufacturing policy issues. As a result of the private sector-academia partnership, autonomous vehicles are receiving a measured and thoughtful level of policy consideration at a critical juncture in their continued development. While essentially still a patchwork of policies with varying degrees of sophistication, states are proposing bills that generally align with federal guidance and future concerns, rather than merely creating reactionary measures that attempt to address an emerging technology's latest crisis.

C. RECOMMENDATIONS

The influence of public policy on emerging technologies is complex. As examples in this paper illustrate, reactionary policy created to address one concern posed by an emerging technology can not only change the trajectory of that technology, but also often creates other unanticipated outcomes. The mere characteristics of an emerging technology, such as its complexity, ambiguity, and unpredictability, make a proper assessment process more difficult for policymakers, though not impossible.²³⁷ What lessons learned from the study of public policy development for UASs and autonomous

²³⁷ Huang Lucheng, Li Xin, and Lu Wenguang, "Research on Emerging Technology Selection and Assessment by Technology Foresight and Fuzzy Consistent Matrix," *Foresight*, 12, no. 2, 2010: 77–89.

vehicles can be applied in an effort to assist stakeholders in the future of additive manufacturing?

There are two approaches to this question: a strategic approach, which focuses on broad themes and general recommendations, and a tactical approach, which proposes specific actions stakeholders could take to better prepare for technology implementation.

1. Strategic

First, organizations need to engage as early in the process as possible. When discussing the concerns raised by nano-technology, authors Haico te Kulve and Arie Rip note, “Engagement is often organized only after a particular issue has emerged, when it may be too late to make a difference.”²³⁸ The FAA’s refusal to update its Model Aircraft Operating Standards is a good example of an organization that simply waited too long to engage stakeholders. With related technologies accelerating all around them, the original advisory quickly became obsolete. Rather than engaging appropriate stakeholders to ensure the policy was consistently updated, the FAA simply ignored it; resultantly, the technology far exceeded the scope of the policy by the time it was revisited. Popular associations, such as the Academy of Model Aeronautics, have not only subject-matter expertise from all over the world, but also an interest in appropriate public policy for their craft.²³⁹ These organizations could have been valuable resources in ensuring this particular policy kept up with emerging technology.

Second, especially when interested in emerging technologies, organizations should engage with non-traditional stakeholders. This is not to suggest that the floodgates should open to all parties interested in a particular topic; there is an important science involved in selecting the appropriate audience to include in early engagement activities. This is especially true of emerging technologies that can be significantly impacted by any small shift in policy or legislation. An increased awareness of actors’ roles and influences should be closely examined before they are included in discussion. As Kulve and Rip

²³⁸ Haico Kulve and Arie Rip, “Constructing Productive Engagement: Pre-engagement Tools for Emerging Technologies,” Department of Science, Technology, and Policy Studies, School of Management and Governance, University of Twente, November 30, 2007.

²³⁹ Academy of Model Aeronautics Homepage, accessed July 9, 2015, <http://www.modelaircraft.org/>.

conclude, “It is thus clear that, although important, more is involved than willingness to enter into a dialogue (or multilogue) with other actors. The propensities to be assessed play a role in the further development and societal embedding of technologies.”²⁴⁰

Third, organizations should cultivate policy entrepreneurs.²⁴¹ Addressing the need for organizations to stimulate individuals to focus on policy issues, Jonathan B. Wiener of Duke University School of Law further explains this concept by describing policy entrepreneurs as individuals who “will develop and test new forms and approaches to regulation for greater effectiveness, less cost, less caustic side effects, and other desirable attributes.”²⁴² This novel approach to public policy development suggests that organizations should identify internal assets to focus on and actually test proposed regulations. This approach would draw on internal organizational subject-matter expertise to help policymakers identify potentially unforeseen issues with multiple policy scenarios. This policy “test-bed” would enable policymakers to choose one proposal, or an individual element of multiple proposals, to ensure the final product is the best overall approach to a given issue.

2. Tactical

DHS has mechanisms currently in place that, if appropriately utilized, could help policymakers understand the potential implications of additive manufacturing and other emerging technologies in the United States. By tapping into these existing resources, the Department could quickly generate a body of knowledge designed to address current gaps in policy, knowledge, and understanding.

DHS should partner with academic institutions via the DHS Science and Technology Directorate Office’s (S&T) Centers of Excellence (COE) to focus on issues related to additive manufacturing. The COE network includes hundreds of universities

²⁴⁰ Kulve and Rip, “Constructing Productive Engagement.”

²⁴¹ David Bornstein, *How to Change the World: Social Entrepreneurs and the Power of New Ideas* (Oxford: Oxford University Press, 2003).

²⁴² Jonathan B. Wiener, “The Regulation of Technology, and the Technology of Regulation,” *Technology in Society*, no. 26 (2004): 483–500.

funded by DHS to conduct research addressing homeland security challenges.²⁴³ Outside of academia, the COE network also includes partners in industry, national laboratories, federal agencies, state, local, tribal, and territorial homeland security agencies, and even first responders. According to S&T, these partners, “work in concert to develop critical technologies and analyses to secure the nation.”²⁴⁴ Issues identified by DHS or its partners can be proposed for study, and awards in the form of research funding can be allocated accordingly. Given the potential—but at this point unclear—impact additive manufacturing could have on the homeland security environment over the next 5–10 years, it would certainly be an appropriate topic for a COE initiative.

DHS is currently responsible for another initiative, which could be used either directly or as a model, to identify ways in which additive manufacturing could impact homeland security. FEMA’s Office of Program and Policy Analysis (OPPA) develops the Strategic Foresight Initiative (SFI) Report. The SFI, which is currently run every five years, is essentially a horizon-scanning effort for the emergency management community. It has worked to gather information on potential trends that could impact the field of emergency management in the next 15–30 years, and does so by working with subject-matter experts in emergency management community and first responders at the federal, state, local, and tribal levels, as well as partners in academia and the private sector.²⁴⁵ The SFI identifies technology as a significant driver of change within the emergency management discipline, but the report’s focus is high level and does not discuss the intricacies of specific technologies.

While this type of report is valuable for long-term planning considerations, the process of polling industry experts to determine issues for further research is even more valuable for short-term issues. Aharon Hauptman and Yair Sharan, researchers at the Interdisciplinary Center for Technology Analysis and Forecasting (ICTAF) in Tel-Aviv, Israel, used a similar process to examine the potential threats posed by emerging

²⁴³ The Department of Homeland Security, Science and Technology COE, accessed, June 5, 2015, <http://www.dhs.gov/science-and-technology/about-st>.

²⁴⁴ Ibid.

²⁴⁵ Federal Emergency Management Agency, *Crisis Response and Disaster Resilience 2030: Forging a Strategic Action in the Age of Uncertainty* (Washington, DC: Department of Homeland Security, 2012).

technologies in 2013. They surveyed over 500 recognized experts on issues related to the threat potential of 33 identified technologies.²⁴⁶ The results of the study provide an entire menu of topics for anyone interested in addressing emerging technology issues. As Hauptman and Sharan note, “The presented process could serve as a basis for a kind of early warning system on emerging threats, which could help coping with them in advance and thus to minimize surprises.”²⁴⁷ What could policymakers want more than to minimize surprise?

D. CONCLUSION

As this thesis shows, finding the appropriate legislative balance when addressing emerging technologies is difficult at best. Reactionary overregulation, which many feared would be applied to additive manufacturing technologies following the successful testing of Defense Distributed’s *Liberator*, could negatively impact the technology’s future by stifling innovation or driving its development elsewhere. Conversely, inadequate policy can create confusion among a technology’s users, which can lead to dangerous operating environments. As noted, it was the absence of FAA policy related to commercial UAS operators that created a potentially dangerous situation between a commercial operator at Falcon UAV and emergency responders in Colorado. While legislative perfection is highly unlikely, avoiding policy-development extremes could drastically improve regulatory overreaction to emerging technologies.

Of the three examples covered in this paper, the approach taken for the development of policy for the continued testing of autonomous vehicles on public roads has been the most successful. To date, it serves as a good example of policy developed from an open partnership between the government and private sector. Furthermore, while the lead federal agency impacted by this technology has an acknowledged appreciation for the potential implications of autonomous vehicles, it has been careful not to burden the continued evolution via unnecessary regulation.

²⁴⁶ Aharon Hauptman and Yair Sharan, “Foresight of Evolving Security Threats Posed by Emerging Technologies,” *Emerald Publishing* 15, no. 5 (2013): 375–391.

²⁴⁷ *Ibid.*

Similar to the UAS policy approach, the current state of policy development concerning additive manufacturing technologies appears to be overly reactionary. At the height of the controversy surrounding Defense Distributed, discussions were ongoing at the federal level regarding legislation that could have seriously restricted the future development of the personal 3D printer. While that legislation never passed, policymakers' approach should concern both those who would like to see increased regulation in the industry as well as those who want less regulation. The knee-jerk legislation and subsequent inaction suggests there is both a lack of understanding and appreciation for the potential implications of additive manufacturing technologies across different industries and sectors. While relatively little policy is currently under consideration, a single significant event could catalyze extreme legislative restriction, swinging the pendulum from non-existent policy to overregulation.

Is additive manufacturing a homeland security concern? Many experts believe, because of its potential for abuse and the ease with which it can be acquired, additive manufacturing is very much a homeland security concern.²⁴⁸ The implications of these technologies are not exclusive to the field homeland security, however, so the solution space is not solely occupied by the homeland security community. As the recommendations proposed in this paper suggest, the homeland security community should be one stakeholder in a larger discussion addressing the ways in which these technologies can be exploited without sacrificing public safety. Several mechanisms are currently in place to foster this dialogue and must simply be directed to do so. Only with increased awareness and communication among appropriate stakeholders can policymakers appropriately address additive manufacturing concerns and avoid the legislative pitfalls so commonly associated with emerging technologies.

²⁴⁸ Ibid.

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